

THE EFFECTS OF OPEN INQUIRY VERSUS GUIDED INQUIRY ON STUDENT  
ACHIEVEMENT AND ENTHUSIASM FOR SCIENCE

by

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Candace Marie McMullan

July, 2014

## DEDICATION

I would like to dedicate this paper to my husband, Andy, who has been ever-supportive of me in my continued endeavors toward education. He has endured and eased the brunt of my stress, and I am ever-grateful for the laughs he gave me during this time. I would also like to dedicate this work to my daughter, Evelyn, who has energized my passion for education. I gain excitement each time I have the opportunity to watch her learn. Lastly, I would like to thank my parents for their constant support and encouragement. They instilled my value for education, and the belief that if you are going to do something, you need to do it well.

## TABLE OF CONTENTS

INTRODUCTION AND BACKGROUND .....	1
CONCEPTUAL FRAMEWORK .....	4
METHODOLOGY .....	10
DATA AND ANALYSIS .....	17
INTERPRETATION AND CONCLUSION .....	39
VALUE .....	43
REFERENCES CITED .....	46
APPENDICES .....	48
APPENDIX A: Discussion Participation Sheet .....	49
APPENDIX B: Interview Questions .....	51
APPENDIX C: Inquiry Education Surveys .....	53
APPENDIX D: Lab Report Rubric .....	57
APPENDIX E: Inquiry Post Test .....	60
APPENDIX F: Cell Theory Open Inquiry Guidelines .....	67
APPENDIX G: Prokaryote Inquiry Directions .....	69
APPENDIX H: Mitosis and Cell Division Inquiry Directions .....	77
APPENDIX I: Cells Unit Test Results .....	87

## LIST OF TABLES

1. Data Triangulation Matrix .....	13
2. Student Opinions on Inquiry Student Opinions on Inquiry .....	20
3. Student Opinions on Lab Value .....	25
4. Variation Among Pre and Post Treatment Interviews .....	29
5. Rubric Comparisons Between Research and Conclusions .....	32
6. Discussion Contributions .....	34
7. Treatment Chapter Discussion Contributions: Comparing Inquiry Groupings .....	35
8. Post Treatment Summative Assessment .....	36
9. Formative Assessment Results .....	37
10. Post Treatment Inquiry Assessment Results .....	38

LIST OF FIGURES

1. Student Opinions on Inquiry Techniques, Strengths, and Weaknesses .....	19
2. Student Opinions on Inquiry Techniques, Strengths, and Weaknesses .....	22
3. Student Opinions on Causes for Poor Grades in Science .....	24
4. Student Opinions on The Value of Lab Reports .....	26

## ABSTRACT

The purpose of this action research was to identify the benefits of inquiry education on student enthusiasm, and abilities to form, analyze, and apply data in a way that allows for thorough conclusions, connections and retention. Open inquiry techniques were being compared against guided inquiry techniques to see which method achieved the best results. To compare these two techniques, three chapters of one unit were used throughout the treatment. The first chapter had all students participate in conducting an open inquiry lab, to grow confident in the expected procedures. In the second and third chapters, students were broken into two groups. One group conducted an open inquiry lab over that chapter's topic, and the other group conducted a guided inquiry lab provided by me. These groups switched their roles from guided to open inquiry or vice versa during chapter three. During the course of the intervention, data were gathered through pre and post intervention surveys and interviews, discussion participation and comments record, formative chapter assessments, a summative unit assessment, a post-intervention inquiry assessment, lab report analysis, and record of student resources. Evidence from surveys, interviews and discussions showed that student enthusiasm for science did increase with the greater use of inquiry; however, their excitement for open inquiry decreased. Students preferred to prepare for, conduct, and complete lab reports over guided inquiry labs because they felt more focused allowing them to learn more from the experience. Students' dislike for lab reports increased throughout the extent of the study. Also, their abilities for drawing thorough conclusions and forming connections did not vary much throughout the lab, but did increase more with guided inquiry. Formative assessments pointed to a more success from students currently taking part in open inquiry; however, according to the summative unit assessment, retention of knowledge was more greatly sustained with the use of guided inquiry. It is clear that the use of inquiry provides many benefits within the science classroom, and both guided and open inquiry forms have purpose. However, my results indicate that guided inquiry is more efficient, highly enjoyed, and maintains greater retention.

## INTRODUCTION AND BACKGROUND

I have eight years of teaching experience within three different schools. Each of these schools has offered me unique classroom responsibilities, and has given me the opportunity to teach Science to all of the grade levels from 1<sup>st</sup> through 8<sup>th</sup>. My current school, Holy Cross, initially hired me as a kindergarten aid, with the intent of having me teach the middle school science, technology, engineering and math (STEM) program the following year. In my first year as a STEM teacher at Holy Cross Lutheran School I taught 5<sup>th</sup>, 6<sup>th</sup>, and 7<sup>th</sup> grade. This program has now evolved to include 6<sup>th</sup>, 7<sup>th</sup> and 8<sup>th</sup> grade. Each grade within our Middle School attends science class three days a week. One of these days is taught by my co-teacher, but the lessons are planned, and work is evaluated by me. Both my co-teacher and I also work with these students every day to teach math, engineering, and technology; as well as provide guidance during study hall. Seeing these students daily, especially during study hall, is a benefit, because it allows more opportunities for assistance with questions relating to any of our subjects, and provides time to give additional support in lab activities.

Though my co-teacher or I see our students daily, we only have around 90 minutes each day to cover science, technology, engineering, and math. In order to compensate for time constraints, a variety of learning levels, and teaching the vast amount of information required, I have begun utilizing flipped classroom methods within my science courses. I began to introduce and apply these techniques early in the year to allow students time to adjust to watching lectures and videos as homework, and utilizing the information within discussions or activities the following day. Thorough lesson plans are necessary to allow for productive and efficient use of our limited class time.



Students at Holy Cross Lutheran School initially appeared to have minimal exposure to an understanding of the concept of inquiry. This was a product of short class times for science, which constricts the amount of labs that can be completed. Also, when labs were completed, it was common for the use of “cookbook” style labs or demonstrations to be utilized. These labs and demonstrations often have a known outcome, and are correlated with a question-answer lab report. Though this method has many strengths, such as focusing on a specific area of content, and its efficient use of class time; there are also areas of inquiry that are lost in this approach. Often, many steps of the inquiry process are conducted for the students, students feel no ownership toward the lab because the observation and questioning components were completed for them, and the shortest, “most-correct” answer is the goal when completing the report that follows the lab. This method removes the critical thinking required from students when they must develop their own question from observations, form a plan to test those questions, and report upon the results they discovered.

#### Focus Question

I am honored to be the individual chosen to begin the STEM program at Holy Cross Middle School. I have a desire to heavily integrate inquiry techniques with goals of achieving an increased understanding of the scientific process, enthusiasm for science within our world, a higher retention of knowledge, and to develop students who are able to present and explain information they have learned. Though I am excited about this opportunity and these many goals, they have caused several questions to form in my mind. Will open-inquiry techniques allow for middle school students to retain and apply concepts covered in their science curriculum? Throughout the process of answering this

question, I hope to discover how to best progress from guided inquiry techniques to open-inquiry methods. Connected with that thinking, I would like to find whether guided or open-inquiry techniques will produce a greater amount of enthusiasm and retention of knowledge from a majority of students. Finally, I need to determine if an inquiry based approach to teaching will be an efficient and effective means for directing students through a middle school STEM program in a way that will allow them to make connections beyond direct observations from the labs conducted.

Through research I attempted to learn which practices would be best to utilize in my study on inquiry. I specifically searched to find several different means of presenting an inquiry based educational approach. I have also tried to find if inquiry will help students see the necessity for the scientific method, and the thorough reporting that coincides with this approach. I had hopes of determining ways in which past researchers have caused students to make the connection between thorough reporting, a personal connection to their project, and a benefit to their retained learning. Finally, I examined the benefits of working with inquiry through collaboration as well as individual research. The attempts and studies of past researchers greatly benefited me in my design of an inquiry based educational study.

The primary focus of my research is to determine: What impact does inquiry-focused study have on students' retention and application of information learned in a middle school science curriculum? Secondary questions will include:

- Does students' enthusiasm for science increase with the application of inquiry?

- Does the open inquiry approach encourage a greater amount of scientific connections when students are drawing conclusions over their lab experiences?
- Does the inquiry approach encourage more research, to help improve questions, hypothesis, and well-developed conclusions within and beyond the laboratory experience?

### CONCEPTUAL FRAMEWORK

The idea of teaching through inquiry has been around since Piaget and Dewey first suggested it around the 1930's (Eslinger, White, & Frederickson, 2008). The means for presenting inquiry education has progressed over the years, and the need for including it within the curriculum has been recognized by the National Research Council, and more recently by the National Academy of Sciences in 2005 (Branan & Morgan, 2010). Past studies have shown that inquiry, when presented abruptly, without methods to prepare students for this teaching technique has a low success rate (Booth, 2001). However, it has also been shown that applying inquiry can improve test scores and help students develop knowledge through problem solving worldly observations by experimentation and analysis (Panasan & Nuangchalerm, 2010). Although many teachers more often choose to utilize guided-inquiry, and/or "cookbook" style labs, studies have shown that these methods can be adjusted in order to prepare students to succeed in open-inquiry situations (Ende, 2012). For success in inquiry education to be achieved, both failures and successes made in past experiences must be observed and analyzed to allow educators to apply techniques deemed reputable.

As stated in the PRIMAS Project, Inquiry Based Learning is a method of teaching that allows students to learn in a way that scientists actually work. This guide goes on to state that most classrooms teach science using methods that do not assimilate the work of actual scientists. Many studies have shown several benefits to Inquiry Based Learning. As stated by Walker (2007) students will have the ability to understand, remember, and apply knowledge better when taught with the inquiry method (Maaß, 2011, p 19) This can be demonstrated through conclusions drawn from lab activities, assessments and knowledge application within coinciding units that take place later in the year, and presentation of the information found from the students' research.

The Rocard report (Rocard, 2007) stated that the inquiry approach promotes higher order thinking skills, and greatly impacts students with lower confidence and learning abilities (Maaß, 2011, p 19). Inquiry is conducive to this because all students are capable of designing and completing a lab at his/her comprehension level. However, the questioning and design process gives students the opportunity to think outside the box, and requires analysis of observations in order to draw conclusions upon what happened within the experiment. Inquiry was also found within the Rocard report (Rocard, 2007), to increase motivation and encourage positive attitudes toward science, while giving students the opportunity to develop many skills involving group work, communication and presentation of information (Maaß, 2011, p 19). Due to the freedom of choice, which inquiry offers, students often enjoy the experiment experience and wish to discuss and share their findings with their peers. These many benefits of inquiry serve as a motivator to design and implement inquiry techniques that will enrich students' classroom experiences.

Even in studies where the implementation of inquiry did not achieve significant gains in student understanding, researchers were able to utilize the results and provide valuable data that are beneficial within other educators' own practices. Some studies of inquiry have indicated that students prefer the use of guided-inquiry labs for several reasons including: less time and effort was needed, students preferred to follow pre-made procedures, and they felt they learned more through the guided labs (Chatterjee, Williamson, McCann, & Peck, 2009). Other studies have shown that when presented with both a guided and open-inquiry lab approach students were able to score higher on post-lab assessments following the guided-inquiry lab (Booth, 2001). However, the same students who scored lower on the post-lab assessments following open-inquiry experience felt that they learned more from those experiences. Many studies have indicated these forms of positive opinions from students. Some students have showed more enthusiasm in sharing their studies and reports when they were able to choose their topic and design an inquiry experiment (Ende, 2012). It was also observed that students were able to see the value of writing thorough and complete lab reports that follow the scientific method after only one experience of attempting to recreate a lab that had an incomplete report (Cacciatore & Sevian, 2006). Hung (2010) found a direct correlation between students' attitudes toward science and their success at inquiry. Students must have a good attitude toward science and inquiry to be successful with it. Studying these combinations of success and failures with inquiry has resulted in the development of several different methods for approaching this technique.

When designing a study on inquiry, successful means of presenting information through inquiry should be utilized. Several different methods have been designed and

applied through past studies, and a common factor has developed from all of these: there is not one perfect method, and a combination of resources often produces the highest rates of success. In their 1996 publication of National Science Education Standards, The National Research Council (NRC) stated, “What students learn is greatly influenced by how they are taught (p. 28).” It is also greatly emphasized in this text that science teaching needs to move the focus away from content and toward the process of conducting scientific techniques. Teaching with one method, and focusing on the facts of scientific content will drive students away from understanding that science is a process of questioning, testing, and discovery through analysis (NRC, 1996).

When introducing inquiry to younger students, techniques involving more guidance are helpful. Some examples, such as the “fishbone” method (Pardo & Parker, 2010), or supporting inquiry with technology (Eslinger et al., 2008) takes students through the steps of inquiry while still allowing them to develop each step through independent and collaborative thinking. The “fishbone” method begins with a teacher-led demonstration that requires students to make thorough observations. They are walked through the steps of identifying a dependent variable, choosing an independent variable, and creating controls in an experiment. The level of independence can be determined and controlled by the educator, but it is stated that it will work best if students are allowed to conduct their own experiment, and record their own results within a self-designed data table (Pardo et al., 2010).

Another method, utilizing computer technology that walks students through the inquiry process, can allow and require students to think independently through the experimental process. This method leaves more time for teachers to lead students through

instruction and/or research (Eslinger et al., 2008). Banerjee, (2010) supports this theory through his 'Learn-Teach-Assess Inquiry' approach. It is made clear that students not only need to conduct inquiry experiments, but they must also conduct research on pertinent information, and be capable of sharing and explaining their results. Marbach-Ad and Claassen (2001) indicate that it is important for students to not only complete the steps of inquiry, but to begin these steps with high-order thinking questions. Well-developed questions will allow for structured research and a well-designed and focused experiment to follow.

Not all inquiry methods require extensive time, which incorporates research and thorough reporting. Brenan and Morgan (2010) recommend the use of mini inquiry-based labs to be used as a form of formative assessment. These inquiry labs combine collaboration with peers, guided questioning from the instructor, and independent conclusions reached by the students within a 40-45 minute lab experience. Students in this situation will be using the information presented by the teacher prior to the lab and applying it to the experience they are observing. Some teachers find that it is most challenging to maintain motivation for labs when the time comes for reporting upon these experiences. Ende (2012) states that the main component of motivating students to create thorough reports is allowing the situation to be relevant to that student. Relevance can come in the form of interest, or it can come in the form of understanding the importance of each component of the scientific process. Students who were required to recreate a lab experience from an incomplete report were able to immediately identify the need for all sections to be thoroughly completed (Cacciatore et al., 2006). Studying these

researchers' experiences can provide useful guidelines for applying inquiry within their own classroom.

Though inquiry has been recognized as a required component to science curriculums for over a decade (Branan et al., 2009), techniques for effectively integrating it are not yet mastered. However, guidelines have been developed based on the experience and observations educators have made over the years. Students should be prepared and practiced at the inquiry approach before being expected to work through it independently (Booth, 2001). Even as students work through independent inquiry projects, research and/or teacher instruction must accompany the experiment for maximum learning to take place. Techniques such as the 'fishbone' method (Pardo et al., 2010) or technology assisted inquiry (Eslinger et al., 2008) can help students visualize their experiment and identify their goal of discovery before beginning their self-designed study. Many techniques, such as allowing students to design their own open-inquiry lab, support that the inquiry experience must be relevant to students (Ende, 2012), that they need to understand the relevance for thorough lab reports (Cacciatore et al., 2006), and a combination of teacher-led instruction/research, collaboration, and student investigation must be used to attain maximum learning. Inquiry is just one component of teaching science, but within this approach there are many methods that can be applied to fit the needs of your group of students. When describing how to develop an inquiry-based science program, the NRC states that teachers must be capable of designing a curriculum, which reaches the interests and current abilities of students by creating lessons that will correlate with their life experiences (NRC, 1996). This technique does not describe



teaching rigid facts from a text; rather it describes educators using flexibility in their practices to best pass on science skills to students.

### METHODOLOGY

I have been fortunate to teach science in many settings within my eight years as an educator. Having many opportunities to engage students, ranging from ages 6 to 13, has caused me to constantly research and revise my methods for teaching. These revisions are made with hopes of reaching a broader range of interest levels, and directing students to strive toward a deeper level of understanding. My personal passion for Science began when I had my first teacher who truly allowed me to learn through discovery. I became frustrated, yet intrigued and challenged, by the inquiry process. In hopes of accomplishing life-long learning experiences with my students, I want to incorporate inquiry and discovery techniques often within my classroom. However, teaching has proven that leading inquiry in a meaningful manner can be challenging and complex. My goals of this Action Research study have helped me feel confident in my methods of presentation of the inquiry technique.

Being responsible for the Middle School STEM program at Holy Cross gives me a strong drive to heavily integrate inquiry techniques within my classroom. This drive is supported by the Next Generation of Science Standards which states, "...students cannot fully understand scientific and engineering ideas without engaging in the practices of inquiry and the discourses by which such ideas are developed and refined. At the same time, they cannot learn or show competence in practices except in the context of specific content" (NRC Framework, 2012, p. 218). Through exposing students to inquiry, I hope to help clarify the scientific process, increase enthusiasm in the field of science, raise

retention of knowledge, and develop individuals that are able to defend and explain information they have gathered, observed, and learned. These desires led me to the question I focused my action research around: What impact does open inquiry-focused study have on students' retention and application of information learned in a middle school science curriculum? I intended to examine this question further by also working to answer these secondary questions: Will students' enthusiasm for science increase with the use of open inquiry techniques? Will the open inquiry approach encourage a greater amount of scientific connections when students are drawing conclusions about their lab experiences? Finally, I worked to determine if open inquiry encourages more self-guided research, to help improve questions, hypothesis, and well-developed conclusions within and beyond the laboratory experience.

### Participants

My study of the open inquiry approach took place with one group of sixteen 7<sup>th</sup> grade students. These students come from affluent families who are generally very supportive of school and homework. This support gives many strengths to the program; however, teacher methods, reasoning, and effectiveness are questioned due to these parents desiring the best education for their children. My goals with this action research study have helped assure and guide me toward effective teaching methods.

The 7<sup>th</sup> grade class is 93% Caucasian and 7% Black American. Twenty-one percent of the class comes from a divorced home and 14% are specifically from a single-parent household. All of the students receive support with their school work and teacher communication with parents is regular. A large percentage of the class take part in extracurricular activities ranging from band, art, theater, clubs, Bible Studies, and

athletics. All of these components work together to form the high-achievement level of this class, encourages more in-class projects, and leads to the effect of successful independent work time.

#### Data Collection and Intervention

From the start of my studies, I had hopes of learning and observing benefits, and/or faults of, open-inquiry education. The use of open-inquiry allows students the opportunity to choose an area of focus for their learning, and to research areas which interest them. When provided with subject guidelines for the units being covered, would the research and tests conducted by students allow for them to learn and apply more information? Or, alternatively, would the freedom that accompanies open inquiry actually cause students to stray too greatly from the necessary points that were to be learned from the unit? Through applying open inquiry to three chapters within one unit, I anticipated observing many changes within my science classroom. I focused my observations on: 1) an increased enthusiasm for the subject of science, 2) more in depth and applicable questions to be tested through inquiry, and 3) well-defended conclusions that are drawn from the data gathered and applied to the unit being studied. I also monitored the amount of time spent teaching the chapters in this way, as compared to the time allotted for each of these chapters last year. This helped me determine if open inquiry is a realistic alternative for completing all the required standards in the limited time provided within the year. Finally, I assessed whether open inquiry allows students to absorb more or less information overall from the chapters being studied. My methods for answering these questions are organized within Table 1 below.

Table 1  
*Data Triangulation Matrix*

Focus Questions	Data Source 1	Data Source 2	Data Source 3
<i>Primary Question:</i> 1. What impact will inquiry-focused study have on students' retention and application of information learned in a middle school science curriculum?	Chapter and unit assessment scores	Student discussions, and conclusions over open and guided inquiry labs	Inquiry Application test
<i>Secondary Questions:</i> 2. Will students' enthusiasm for science increase with the application of open inquiry?	Surveys prior to and following the intervention	Record of discussion participation	Student interviews prior to and following the intervention
3. Will the open inquiry approach encourage a greater amount of scientific connections when students are drawing conclusions over their lab experiences?	Lab reports from guided-inquiry labs	Record of discussion participation, and types of contributions given	Reports of individual inquiry labs
4. Will the open inquiry approach encourage more research, to help improve questions, hypothesis, and well-developed conclusions within and beyond the laboratory experience?	Record of the number of videos and resources utilized during the comparison and intervention chapters	Evaluated questions, hypothesis, and conclusions from guided and open inquiry lab experiences	Student discussion applications pertaining to information learned during research to prepare for the inquiry experience.

Prior to the start of the unit being used for my study, students completed a survey to evaluate their current feelings about science, labs, and student-led projects. I also interviewed eight students at this point. These eight students were a mix of males and females. I chose four students who appear to be excited about science, work hard in class, and currently carry strong grades. The other four students were students who are hard to excite, tend to fall behind on projects, and were currently carrying a low score in

science. This interview was repeated at the completion of the study to see if their feelings changed from the activities that took place.

In order to have a comparison, I conducted my action research over three chapters. The first chapter covered cell theory, chapter two was over prokaryotes, and the third chapter laid out the steps of mitosis. Each chapter was to be completed in three to four weeks. Students knew the chapter topics prior to the start of the chapter, so they had plenty of time to come up with an applicable and testable question that related to our current area of study. The first chapter was utilized to help familiarize the students with the open inquiry approach. All students conducted an individual, open-inquiry project over the chapter topic presented. If their questions were similar, students were allowed to work on the lab together. They expressed a strong desire to work in this way, and our limited resources allowed for this approach to work better than 16 independent labs occurring simultaneously. Students received guidance in developing a strong question for this first chapter, in hopes that it would prepare them to develop questions successfully and independently in later chapters. As we worked through the chapter, students had 1 to 2 days each week to discuss their project with classmates, research, and/or conduct experiments. The days not spent working on inquiry studies were used to take notes, watch videos, and observe demonstrations relating to the topic. During the second chapter, the class was divided into two groups. Eight students (group A) conducted their own open-inquiry study, while the other eight, (group B) completed guided inquiry labs provided by me. Students again had 1 to 2 days each week to research, conduct labs, discuss labs, and develop conclusions. Group B was given their guided inquiry lab directions in advance. This allowed them the opportunity to read over the lab, research

the concepts being covered, and develop strong hypothesis prior to conducting the lab. During the third chapter, group B conducted their own open-inquiry study, while Group A worked with the teacher-provided guided-inquiry lab. The same methods that were used in chapter two were continued throughout our studies in chapter three. Beyond the information found in the labs, all of the students received the same notes and resources to be used as research and study tools. I attempted to keep record of how many resources students used each chapter to help them learn the information. My hopes were that tracking this information would help me recognize any correlations between the open inquiry approach and a motivation to conduct research.

Throughout each chapter, short formative assessments took place through essay questions over the essential concepts covered in the chapter, completion of online exploration activities that outline the information covered, and/or the use of digital labs and their corresponding guided reports. The results of groups A and B were compared to determine which method of inquiry, if any, helped achieve higher scores throughout the chapter work. At the close of the unit, a summative unit test was given, and students' test scores were evaluated to see within which chapters they scored the highest, and if those questions correlated with their open or guided inquiry studies. A test on inquiry abilities developed by the state of Indiana to prepare students for the Inquiry portion of the ISTEP test was included at the conclusion of the unit assessment. Inquiry skills were evaluated at this time. Also, to observe for growth within these inquiry abilities, students' 6<sup>th</sup> grade Indiana Statewide Testing for Educational Progress (ISTEP) scores were evaluated and compared to their recent inquiry capabilities.

To observe student enthusiasm, application of scientific knowledge, and connections made during lab experiences, we had class discussions on the day following each lab. Student participation was recorded with a checklist that includes types of comments shared (simple agreements, off-subject comments, discoveries made through the lab, discoveries made through research, conclusions drawn, defense to conclusions, and other), and a quotes and observation section. These discussions were conducted as a whole class, and comparison between open and guided-inquiry group participation was made. Also to observe student enthusiasm, students were again asked to complete the survey on their feelings toward science, projects, and labs. To monitor for any change in student opinions about science, labs, and other learning techniques, I also repeated the interview with the same eight students interviewed at the start of the study. The post-treatment surveys and interviews were identical to those given prior to treatment.

In addition to the tests for inquiry application, I observed students' application of knowledge through inquiry by examining their lab reports. Three sections of the lab reports were most strongly evaluated: the question, hypothesis, and conclusion. Each of these sections was evaluated by a rubric. This rubric is designed to help me determine the depth, correlation, and testability of the question developed; the amount of research conducted prior to the formation of the hypothesis; and the relevance and defense given to support the conclusions drawn from observations made during the lab. Both open and guided inquiry reports were evaluated with this rubric. These data were then used to pinpoint correlations between type of lab conducted and the strength of the report that followed.

Between the use of student interviews, student surveys, record of discussion participation, record of resources used, evaluated lab reports, inquiry test results, formative chapter assessments, and a summative unit test, I had a large gathering of evidence to use toward analyzing the level of value for inquiry education.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained.

## DATA AND ANALYSIS

Analyzing data gathered through the extent of the study revealed many surprising results. Growth of concept knowledge and inquiry methods was easily observed, but where my personal observations caused me to note increased enthusiasm, comprehension, and efforts within inquiry, alternative data sources indicated a decrease in these areas. The Inquiry Education Survey, used to evaluate student enthusiasm for science, was one of the especially enlightening and interesting pieces of data.

### Evaluation of Student Enthusiasm

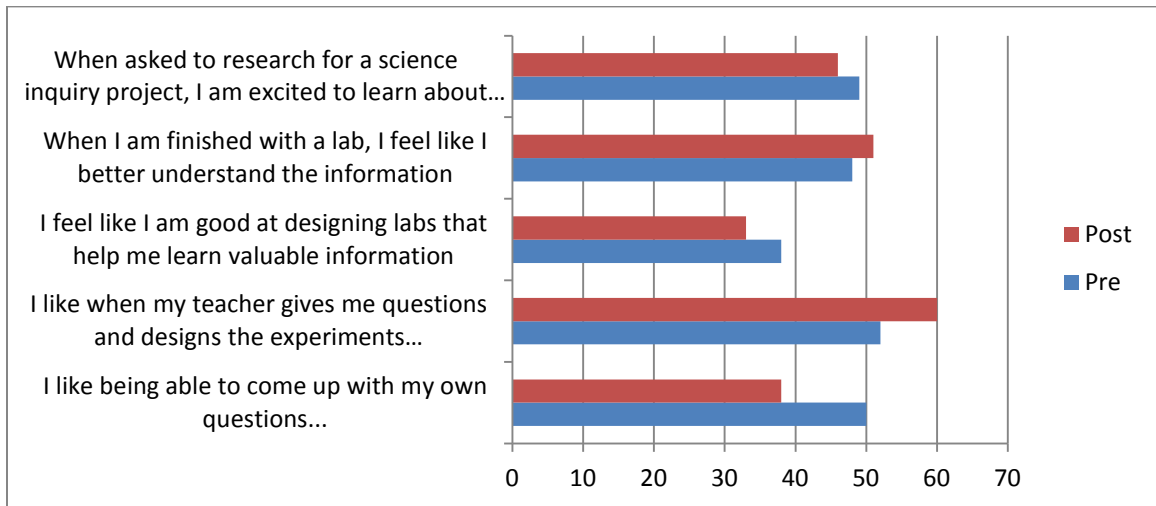
#### Results of the Inquiry Education Survey

The Inquiry Education survey, as shown in Appendix C, was given both pre and post treatment. The questions did not vary, and students were made aware that their honest answers would in no way effect their grade. The pretreatment survey results were not surprising to me. Higher level students stated science was fun, and they felt that they could learn the information easily, or with the guidance given to them. Low level students found science to be harder for them to do well as compared to other subjects, or, stated that the subject was, "Easy, but boring." Also as expected, 63% of students said that they



enjoyed lab days ( $N=16$ ). However, only about 50% stated that they felt they learned a large amount from labs. Prior to the start of treatment, 82% of students claimed they saw the value behind lab reports, regardless of their feelings toward writing the reports. Ten of these students chose the statement, “Lab reports are a lot of work, but help me see the value of the lab.”

This survey asks students’ opinions on their learning style, reasoning for success or failure, the value of lab days and types of labs, and how successful they feel they are with creating, completing, and reporting upon open-inquiry labs. When evaluating these surveys, I analyzed similar components of the survey to allow direct comparisons of variation among the students and group as a whole. As seen in Table 2 below, when students were asked to rate their opinions on conducting inquiry prior to the intervention, the majority gave positive feedback. However, the surveys were repeated post-intervention, and all opinions on students’ ability with open inquiry decreased. This is visualized in Figure 1



*Figure 1.* Student opinions on inquiry techniques, strengths, and weaknesses. Ratings determined by multiplying the Likert scale rating (1-4) by the number of students who chose that rate ( $1N + 2N + 3N + 4N = R$ ). The sum was then found of those products to score a final rating. The results are shown above. ( $N=16$ ).

The largest decrease was seen in the joy students had at developing their own questions for an open-inquiry experience. As a group, students' opinions on this topic had a variation of -12; meaning the sum of the ratings granted to this question dropped twelve points within the pre and post surveys. At the start of the intervention it was deemed mostly true that the majority of the class liked developing their own question. The -12 variation indicates that their feelings toward this task has digressed to only being, "somewhat true." However, the joy of all forms of inquiry was not lost. When asked to rate their opinions on conducting a lab developed by their teacher, the group awarded this area with the highest rating in both pre and post assessments. This section had a variation of +8; meaning its rating went from mostly true to completely true. Unfortunately, this +8 also indicates that students more greatly prefer guided inquiry as opposed to open inquiry. The fact that this question had the highest rating within both the pre and post-

intervention surveys indicates that they already had these feelings prior to the experience, and the additional labs only heightened these opinions. A positive correlation I found through analyzing this piece of data was that students' opinions on understanding information better after conducting a lab was highly rated. Overall the group rated understanding more after completing a lab as, "mostly true, and this rating even had a variation of +3 by the post-intervention surveys. This indicated a slight increase in students' recognition of the value of the lab experience, regardless of its format.

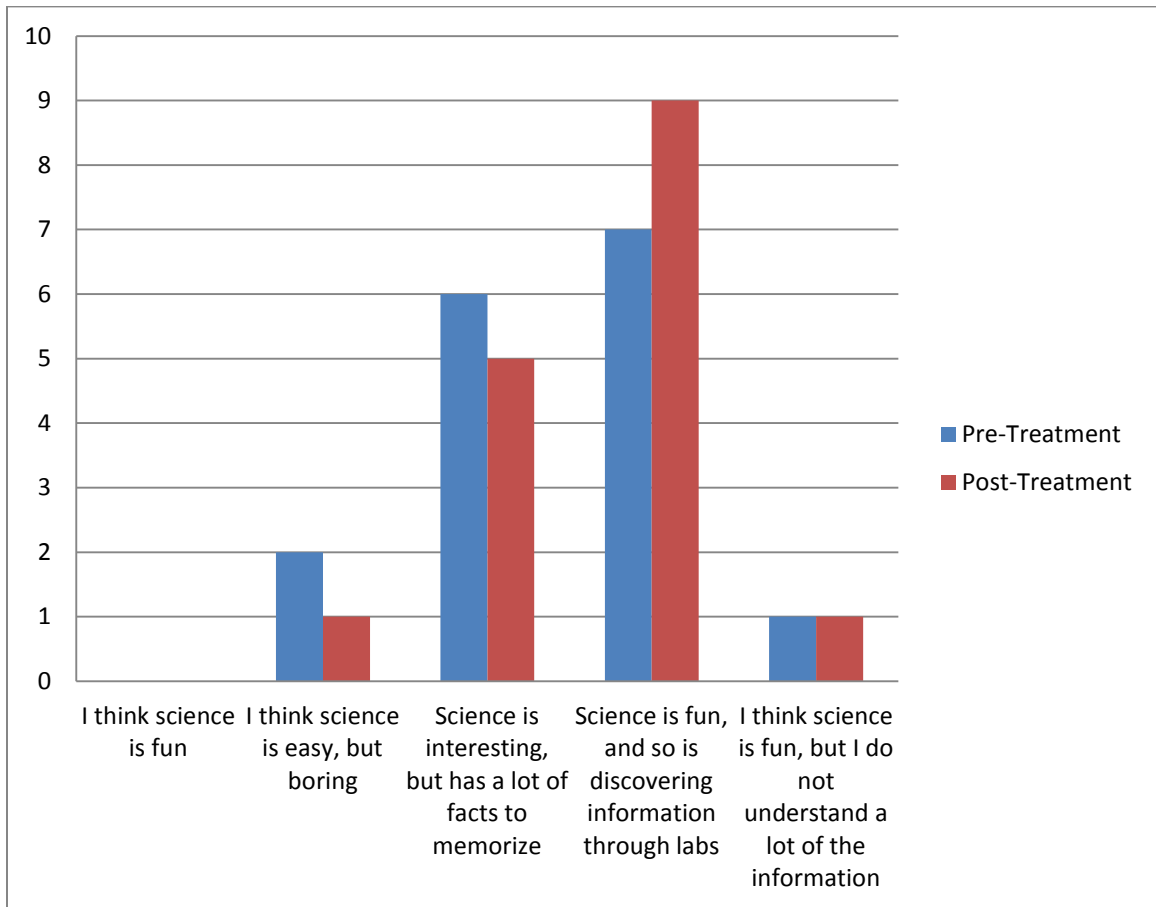
Table 2  
*Student Opinions on Inquiry*

Rating	I like being able to come up with my own questions...		I like when my teacher gives me questions and designs the experiments...		I feel like I am good at designing labs that help me learn valuable information		When I am finished with a lab, I feel like I better understand the information		When researching for inquiry, I am excited to learn about something that interests me	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	1	2	0	0	2	4	1	0	0	0
2	4	7	4	1	8	7	3	3	4	6
3	3	6	4	2	4	5	7	7	7	6
4	8	1	8	13	2	0	5	6	5	4
Total	50	38	52	60	38	33	48	51	49	46
Variation	-12		+8		-5		+3		-3	

*Note.* 1=Not at all True, 2=Somewhat True, 3=Mostly True; 4-Completely True. Total values for each question were found by multiplying the number of students that chose each rate, by the number representing that rate, and finding the sum for each question ( $n_1 + n_2 + n_3 + n_4 = R$ ). Variation represents the difference between the total values for each question within the pre and post intervention survey. ( $N=16$ ).

The question in the pre and post treatment survey concerning students' feelings toward science was interesting, encouraging, and yet contradictory toward the other questions over inquiry. No individual chose, "I think science is fun," in either the pre or

post treatment surveys. However, 44% of students chose, “Science is fun, and so is discovering information through labs,” during the pre treatment, and 56% of students chose this response in the post-treatment. It was encouraging to see an increase in the joy for science, and lab discovery by this response. The second most popular response at 37% was, “Science is interesting, but has a lot of facts to memorize.” I am not surprised by this response as both surveys were taken by the students within the same week of a unit test. The Cells unit we covered during the treatment was especially large, extended for a long period of time, and covered a wide berth of information. Due to these factors, I anticipated for this response to increase in popularity, but in actuality, it decreased by one student in the post-treatment survey. The only other category to decrease over the unit was the response, “I think science is easy but boring.” This response decreased from two students to one.



*Figure 2.* Current feelings students have toward science during pre and post treatment, ( $N=16$ ).

When analyzing the data from the question, “What do you think most helps you succeed in science?” it was encouraging to see that students truly valued the variety of activities in class. A large majority of students chose that they were most successful when they have a teacher willing to put in effort, complete projects and labs, and take notes over a unit. Rather than pinpointing one method for their learning, students chose that they preferred the full expanse of techniques to absorb the material. The student that stated she was not successful in science mentioned this within her interview as well. She stated, “I enjoy science, like listening to it in class, but I feel like I’m not very good at it.”

She also chose, “Even if I try very hard, I do not do as well in science as in other subjects.” When asked what could be done to help her learn the material better, she responded with, “I like what you’re doing now. I think it’s fun, and we do a lot.”

When asked what caused students to be more successful in science, I felt it to be encouraging that, “My teacher teaching the information well,” went from the most popular response at 44% to a low-level response of 19%. By the post-treatment survey 63% of students chose that they feel most successful when they get to work with a group throughout the unit so other students can explain and discuss the information in words they can better understand. When this was elaborated on in open-ended questions and interviews, students still liked labs and projects; they simply prefer them when they are in groups. They expressed feelings of learning more through collaboration, and being able to utilize this to help them better understand observations. Several students also stated that they wished there was more time to prepare for and conduct labs, have discussions over labs and projects, and discuss unit essential questions as groups or as a whole class. It is exciting to hear a desire for collaboration, and responsibility for learning; venturing the sole responsibility away from the teacher.

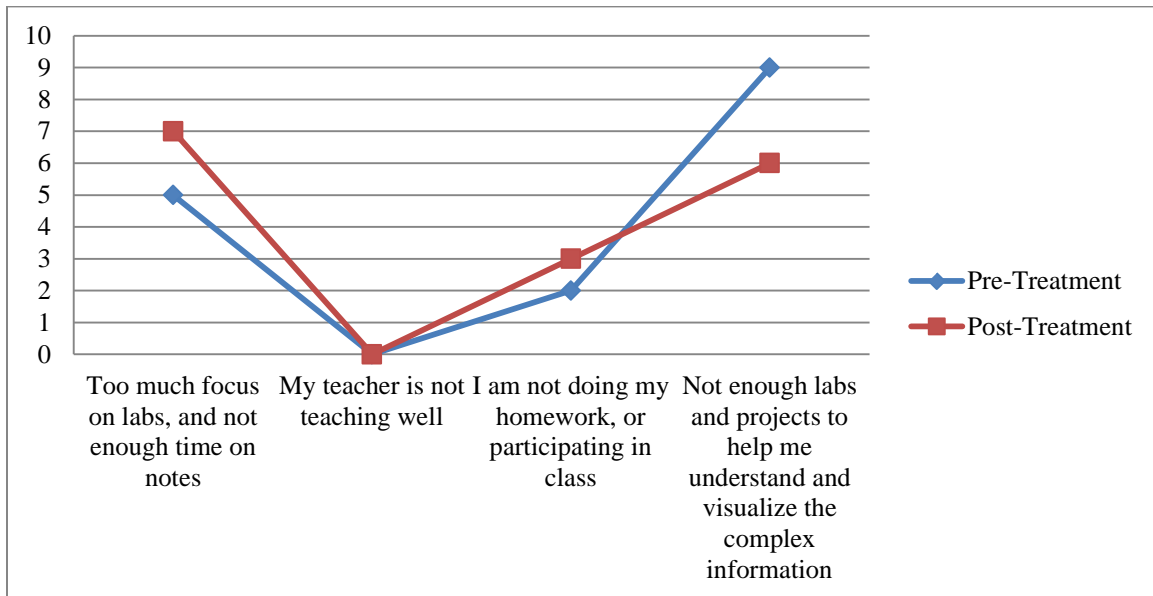


Figure 3, Student opinions on causes for poor grades in science,  $N=16$ .

As shown in Figure 3 above, the study began with the majority of students, 56%, feeling that if they were not doing well in science it was due to there not being enough labs and projects to help them better understand this information. Unfortunately, by the post-treatment survey, this feeling had shifted. Now only 37% of students felt they needed more labs and projects; whereas, 44% of students now felt that there was too much focus on labs and not enough time with notes. Only 19% of students took personal responsibility for lacking grades, by choosing the response indicating that they were not completing homework or participating in class. This shift in the desire for inquiry, partnered with 25% of students admitting that lab days were, “stressful, and therefore not helpful,” as shown in Table 3, indicates the presentation of this study took away some of the previous excitement felt by inquiry activities. As for the rest of the class’s feelings toward lab days, the majority still claimed that labs were fun and helpful in both the pre and post-surveys. However, this number did decrease from 63% to 50% over the extent

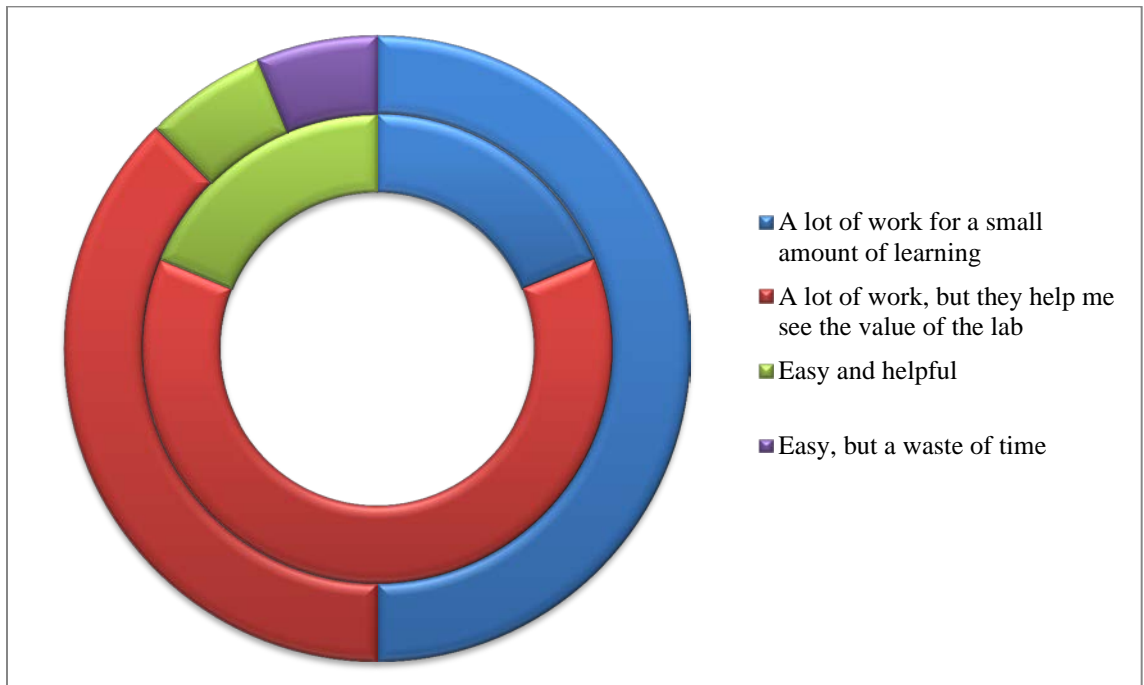
of the treatment. Also in the post-treatment survey, 25% of students indicated that lab days were fun, but not helpful in learning the information. This was an increase of 6% from the pre-treatment surveys.

Table 3  
*Student Opinions on Lab Value (N=16)*

Question: Lab days in school are...	Pre-Treatment	Post-Treatment
Fun and I like them because I do not have to work very hard that day	0	0
Useless. I do not learn from the experience, and have to waste my time writing a report.	0	0
Fun, but not helpful for me when it comes to learning the information we are studying	3	4
Fun, and helpful	10	8
Stressful, and therefore not helpful to me	3	4

The question pertaining to the value of lab reports was the most discouraging in the post-treatment surveys. Prior to the treatment, only 19% of students stated that the reports were a lot of work for a small amount of learning, and 63% stated that they were a lot of work, but helped show the value of the lab. By the post-treatment survey, 50% of students indicated feelings of a high work load for a low return, and one student even chose that lab reports were, “Easy, but a waste of time.” Of the 63% that stated they recognized the valued of lab reports in the pre-treatment, only 38% maintained this feeling in the later survey. Those who felt that lab reports are, “Easy, and helpful,” also decreased from 19% to 6%.





*Figure 4*, Student opinions on the value of lab reports. The inner ring indicates pretreatment data and the outer ring is post treatment,  $N=16$ .

### Results of Student Interviews

In the open-ended survey questions and interviews, students indicated that they found more value in pre-made lab reports that guided them through the procedures, and questions to answer. They stated that this guidance helped them to better focus on the purpose of the lab, and the questions helped them to see what they should have learned. When interviewed about the level of learning students feel from guided inquiry labs, one student stated, “I definitely learn a lot from the ones you created because everything is already set out and there is just time to learn.” The lab reports for open-inquiry labs are much more open-ended. The interview brought to my attention that this can be a stressful situation, even for students who enjoy labs. One such student stated, “I do learn a lot, but there’s also a lot of stress going on at the same time.”

When asked to report upon lab results and conclusions, students are simply to summarize their data within written results, and then write a four-part conclusion that includes:

- Was my hypothesis correct or incorrect and why?
- What did you learn through research and observations from this lab (3 or more items relating to the unit)?
- What was the room for error, and how could it affect your results?
- If you could repeat or revise the experiment, what would you do differently and why?

From the teacher's perspective, this format has a lot of benefits, including practicing independent proper analysis of data. However, for students uncertain of what conclusions they are supposed to draw, this format is highly challenging. Their answers are often vague, the section over what they learned is typically very short and not elaborated upon, and many misconceptions are stated. Though the required format for the guided inquiry conclusions were congruent, students felt they were easier due to the coinciding questions and guidance about the purpose of the lab.

Table 4 represents the variation between my pre and post intervention interviews. Students were honest with their responses allowing me to see areas of growth or decreased enthusiasm among each individual. Student responses were awarded a -1, 0, or +1 according to whether they were against inquiry, neutral toward it, or in favor of it respectively. The sum of these responses was then found among the students to look for trends and variations throughout the extent of the study. As shown in Table 4, the interviewees' overall feelings toward science scored a sum of +3, with a variation of +2.

That indicates that even though students were tired by the close of the unit, on average the groups' feelings toward science became more positive. Interestingly, all areas of the interview showed growth relating to inquiry throughout the unit, except for the two questions pertaining to open inquiry. These questions, "Do you like creating your own labs?" and, "Do you feel like you learn a lot when you conduct these labs?" Both scored with negative or neutral feelings in the post interview. Also, the variation from pre to post interview was negative for both of these questions, indicating that students' feelings toward open inquiry became more negative throughout the expanse of the study. One student's answer progressed from, "I do like creating my own labs. I think it's fun." To, "Umm, I think it's fun to make my own labs, but you get really confused." This answer expressed the feelings of the majority of the interviewees. They do not dislike conducting their own labs, because they still enjoy lab days, but they are more confused or stressed on days when they are responsible for the entirety of the lab.

The questions within Table 4 that referred to students preferred learning methods indicate that throughout the progression of this study more students recognized that they enjoyed the use of inquiry as a means for learning their material. Students had to specifically indicate labs as a means for learning information to receive a +1 rating within this table. As shown, this occurred several times, and increased with our heightened use of inquiry. One student responded, "I like doing group labs because you get to actually see it happen in front of you instead of just hearing it ." and another stated, "I like all the labs we do, I especially like it when you make the labs for us. I feel like it's easier and you can learn more from them." These responses were highly encouraging toward the continued use of inquiry.

Table 4  
*Variation among Pre and Post Treatment Interviews (N=8)*

Question	Overall Feelings	Variation
What are your feelings toward Science?	+3	+2
What is your favorite way to learn our science material when we are in class?	+5 Lab Positive	+3
What methods help you to learn our material best?	+4 Lab Positive	+3
Do you like creating your own labs?	-1	-4
Do you feel like you learn a lot when you create your own labs?	0	-6
Do you enjoy doing labs I create?	+8	0
Do you feel like you learn a lot from these labs?	+8	0

*Note.* Feelings against inquiry = -1, Neutral feelings = 0, Positive feelings toward inquiry = +1. Table represents the sum of post interview responses and the variation indicates if this was a positive or negative change throughout the intervention, in reference to open inquiry.

### Discussion Participation

Student discussions were interesting and revealing. We completed class discussions at the close of each lab. The goal for the discussion data was to pinpoint if students were enthusiastic about science, through active voluntary participation. The types of comments shared were also analyzed to show if students were applying their knowledge gained from both research and observations made within their own personal labs to form scientific conclusions and applications beyond the laboratory experience. In order to best analyze this, the types of comments contributed were recorded within the Discussion Participation Sheet (Appendix C). The value of the discussions, willing participation among students, and a strong desire to speak increased with each discussion. These data may appear misleading in this way when, as Table 6 clearly shows, the third

discussion only had 26 total comments. However, this was due to a limited time-frame for the discussion to take place, and because students' comments were thorough. The class was disappointed when we were out of time, and they wished for more time to share their results and frustrations with the lab.

Within the first discussion, students more commonly shared their observations, but did not tend to elaborate upon why they believed they saw that occur. The first discussion was also very closed among students. They spoke about their own individual lab, but had no connections or debates about other students' data and conclusions. However, both the second and third discussions had several points when students would agree or disagree with one another's data, and then would defend it with their own observations or research. These discussions were much more exciting, and all the students clearly felt drawn to participate. There was 100% participation among students, and everyone had a strong desire to speak within the final discussion. It must be noted that students who participated in guided inquiry labs did share a higher percentage of conclusions and applications within their discussions.

Data from surveys, discussions, and interviews greatly support the increased enthusiasm among students with the use of inquiry. However, this increase was only supported by guided inquiry data, and directed that students' enthusiasm actually decreased throughout the intervention with the use of open inquiry. Lastly, students indicate feelings of enhanced learning through the use of inquiry.

Evaluation of Motivation to Research and Apply Knowledge within Open and GuidedInquiryLab Report Analysis

In hopes of seeing a correlation between heightened research and open inquiry, the number of resources used for research was tracked. Students were given class time to research, but it was paired with forming their question, hypothesis, and lab procedures when conducting an open-inquiry lab. This portion of the process was often confusing and stressful for the students. Many students were not confident in the questions they formed, and therefore were uncertain as to how to research. Last minute revisions were made on lab days and due to a small number of supplies, many students with similar questions would pair up to conduct their labs together. The observations and data analysis would still occur independently, but students appreciated the collaboration opportunity.

Though research days were not always productive for all students, there was typically a correlation between high research rubric scores, and high conclusion scores. This is an anticipated connection, because without a depth of background knowledge, it is challenging to apply data to knowledge beyond the direct purpose of the lab. However, both groups had a slight decrease in thorough research when conducting open inquiry work.

Table 5  
*Rubric Comparisons between Research and Conclusions (N=16)*

Student	Comparison (Open)		Treatment (Guided)		Treatment (Open)		Variation in Treatment (Guided to Open)	
	R=4	C=12	R=4	C=12	R=4	C=12	Source	Conc.
Group A Avg	2.4	9.8	2.3	9.8	2.1	8.7	-0.5	-10
Group B Avg	2.8	9.1	2.7	8.6	2.3	9.1	-3.5	+4
Total Averages	2.6	9.6	2.5	9.2	2.2	8.9	--4	-6

*Note.* R=4 indicates the total possible points to earn for utilizing resources. 4=More than three, used to form hypothesis, and summary is in student's words; 3=Three resources, used to form hypothesis, and summary is in student's words; 2=Fewer than three resources, not all are reputable, not used to help form hypothesis, and summary is in student's words; 1=Fewer than three resources, not used to help form hypothesis, and information is copied; 0= no sign of research. C=12 indicates the total possible points to earn for strong conclusions, connections, and applications.

There was no pertinent correlation between type of inquiry used, and amount of background research conducted by the students. However, increased background research did correspond with stronger conclusions.

#### Evaluation of Abilities to Apply Data toward Conclusions in Guided and Open Inquiry

##### Lab Report Analysis

It is challenging to figure out how to encourage students to form deep and thorough conclusions that connect research and data to their variables. In order to evaluate their abilities and growth in this area, lab reports were analyzed using the Lab Report Rubric focused on the question, hypothesis, and conclusion (Appendix D). The hope was that there would be a larger increase with forming strong conclusions within the open-inquiry labs, as they would be more invested in the questions they chose. However, rather than seeing a large difference between conclusions and overall lab scores from open to guided inquiry, constants were identified. Students who were strong at drawing conclusions, analyzing data, and making connections did well regardless of lab format.

Surprisingly, weaker students typically performed better with the open inquiry format, but most lost points for lack of background research. When comparing the rubric scores for Groups A and B to look for consistent growth or decrease with writing successful conclusions when paired with open or guided inquiry labs, the data was contradictory. The success rate of Group A decreased by a summative value of 10 when comparing their guided inquiry labs to their open inquiry labs; whereas Group B increased by a value of 4. This is especially interesting to note, because overall learning success rate is fairly equal among the two groups; this evidence simply is another indicator of the vast difference within their learning styles. However, a connection between the groups can be identified. As seen in Table 5, when class conclusions were analyzed, there was an overall decrease in open inquiry conclusions as compared to guided inquiry scores.

#### Discussion Participation and Conclusions

The discussions were enlightening toward students' ability to draw conclusions and apply data beyond the lab experience. When examining Table 6 and Table 7 below, it was encouraging to see that mundane discussion participation, in the form of simply agreeing or disagreeing with previous statements or repeating comments, decreased with each discussion. Therefore the number of observations, conclusions and applications increased as discussions continued. Willingness and desire to share observations and personal lab experience showed that the experience was memorable – whether due to joy or frustration. The second discussion had the highest number of conclusion and application discussion pieces. This was likely because multiple groups had developed conclusions that contradicted one another, due to conflicting data. This caused many students to inference about reasoning behind the bacteria formations, and defend the



conclusions they had developed. This questioning of one another's results then steered the discussion toward information that was found during research, allowing for misconceptions to be discussed, a debate to occur about whose data was likely accurate, and whose was faulty due to a contaminated petri dish. This discussion was extremely enthusiastic and full of connections and application of researched knowledge. It was a wonderful tool to help clear up misconceptions that had occurred during the lab experience.

Table 6  
*Discussion Contributions (N=16).*

Discussion	Total Number of Comments	Agree/Disagree/Repeat	Observations	Conclusions/Applications
1 – Cell Theory	39	46%	23%	31%
2 – Prokaryotes	43	19%	23%	58%
3 – Mitosis	26	12%	42%	46%

When examining the data further to determine participation strength between the guided and open inquiry groups, the numbers pointed strongly in one direction. In both treatment discussions, the guided inquiry group had a higher number of conclusions and applications within their discussion participation. These data can be viewed in Table 6, and are especially noteworthy because they are not indicating that the dominant personalities of the class controlled and contributed to the discussion. Rather, data indicate that when students did speak, there was a higher amount of valuable information shared from the guided inquiry participants. The mitosis discussion had a higher percentage of observations shared by open inquiry participants. However, there was a much lower correlation between sharing these observations and making any connections to them. This shows that there is still likely a gap between the data and comprehending

the meaning of those data. Regardless of which test group students were a part of, the discussion that followed lab days was a wonderful opportunity to clear up areas of confusion, and make connections they may have missed when working through their lab independently. They also enjoyed sharing their lab design, and what discoveries or frustrations they came upon throughout the process.

Table 7

*Treatment Chapter Discussion Contributions: Comparing Inquiry Groupings (N=16)*

Discussion	Total Comment Contribution		Agree/Disagree/Repeat		Observations		Conclusions/Applications	
	Open	Guided	Open	Guided	Open	Guided	Open	Guided
2 : Prokaryotes	47%	53%	11%	7%	9%	14%	26%	33%
3 : Mitosis	50%	50%	4%	8%	27%	15%	19%	27%

Lab report analysis and discussion participation show evidence that guided inquiry allows students to learn information at a level that enables them to make stronger conclusions and applications with their data and observations. Data indicate more success with guided inquiry than open inquiry in the formation of conclusions.

#### Analysis of Effective Learning Through Inquiry

##### Summative Assessment Scores

One method for testing effective learning and application of knowledge through use of open inquiry was analysis of students' summative unit assessment, Cells Unit Test (Appendix H). At first glance, data from the assessment did not seem to indicate any trends between inquiry teaching methods and test scores. However, once the data were grouped according to subject matter and treatment groups, distinct correlations emerged. As Table 8 shows, the data were broken into: total scores, pretreatment chapter (where all

students conducted an open inquiry lab as practice), the two treatment chapters, and the remaining post treatment chapters. The lowest average scores came from the post-treatment chapters, indicating a positive trend for the general use of inquiry. However, when looking at the treatment group averages for the two treatment chapters, there was evidence to supporting guided inquiry's effectiveness over open inquiry. In each of the two chapters' data, the guided inquiry's group average was approximately five percentage points higher. The averages of the total scores indicated that the two groups' overall achievements were similar, giving additional continuity among the data.

Table 8  
*Post Treatment Summative Assessment (N=16)*

Student	Total Score Q = 57	Cell Theory & Differentiation (Pre Treatment) Q = 15	Prokaryotes (Group A Treatment Chapter) Q = 7	Cell Cycle and Mitosis (Group B Treatment Chapter) Q = 10	Remaining Chapters Q = 25
Group A Avg	79.9%	80%	73.7% Open	92.9% Guided	77.1%
Group B Avg	77.5%	77.5%	78.6% Guided	86.3% Open	72.5%
Total Avg	78.7%	78.7%	76.3%	89.3%	74.7%

*Note.* Table shows data for total scores, pre treatment and treatment chapters, correlation between form of inquiry, and test scores, and average scores for chapters completed post treatment. Q = the number of questions for each section of the test.

#### Formative Assessment Scores

The summative assessment results were especially interesting when comparing it to the data for the formative assessments. Students completed an open-note and resource essay question for the pretreatment chapter, as well as the chapter covering mitosis, whereas they completed a digital lab paired with comprehension questions to help prepare them for the chapter covering bacteria growth. These assessment activities took

place during the research and preparation for the chapter's lab activity, but prior to the completion of the lab report. Therefore, the data are not indicative to what they learned from conducting the labs, but rather indicate efforts put into researching prior to lab completion. As the Table 9 shows, this data contradicts the data from the summative assessment. Students preparing to participate in the open-inquiry lab scored higher on both forms of formative assessment during treatment phases. The open inquiry group for the prokaryotes lab averaged over 7% higher than the guided inquiry group. The cell cycle and mitosis assessment had a gap that was slightly less than 4%, but also indicated higher scores for the open inquiry group. This may indicate a higher amount of information being absorbed from background research by the open-inquiry group. This would be logical, as they needed that research for their lab development. However, as the previous data show, this information was not retained as well within the summative assessment.

Table 9  
*Formative Assessment Results(N=16)*

Name	Cell Theory & Differentiation (Pre Treatment) Q = 20	Prokaryotes (Group A Treatment Chapter) Q = 20	Cell Cycle and Mitosis (Group B Treatment Chapter) Q = 10
Group A Avg	87.9%	92.9% Open	72.5% Guided
Group B Avg	82.5%	85.6% Guided	76.3% Open
Total Average	85%	89%	74.4%

*Note. Q = number of points allotted for the assessment.*

### Inquiry Post Test Scores

Overall, the Inquiry Post Tests (Appendix E) taken post-treatment were pleasing and not surprising. The students who scored a low average on the assessment align with

the students who are generally weak in science. These students struggled the most with the data analysis and application components of the assessment. This is logical, as applying scientific reasoning to data and lab experiences is an advanced skill. The lowest average component of the test for the class, as visible in Table 10, was the portion that assessed for value of data organization. The class averaged a 70% on this portion of the test. This may not be an accurate reflection because there were only two possible points within this area. However, the answers given by students as to why charts and graphs should be used to reflect data do indicate that this is an area with room for a large amount of growth. One student responded to the question, “Why did Laura put her results in a table and graphs?” with, “To look more professional...,” and another one stated, “Laura did that because she had to keep her information in order from least to greatest.” This second response was most disconcerting because organizing the data from least to greatest had no benefit in its analysis. The majority of the answers indicated that students knew both charts and graphs should be utilized, but that it was simply an additional requirement rather than an additional valuable component of data analysis.

Table 10  
*Post Treatment Inquiry Assessment Results (N=16)*

	Total Score Q=22	Organizing Data Q=7	Reading Charts & Graphs Q=3	Data Analysis & Application Q=10	Value of Data Organization Q=2
Averages %	85%	6.1 = 87%	2.6 = 87%	8.6 = 86%	1.4 = 70%

*Note. Q = number of questions present within the specified section.*

## INTERPRETATION AND CONCLUSION

The focus of this action research was to determine what impact inquiry-focused study would have on students' retention and application of information learned in a middle school science curriculum. To best determine this large area of focus, the concepts were broken into three secondary questions: Will students' enthusiasm for science increase with the application of open inquiry? Will the open inquiry approach encourage a greater amount of scientific connections when students are drawing conclusions over their lab experience? Will the open inquiry approach encourage more research, to help improve questions, hypothesis, and well-developed conclusions within and beyond the laboratory experience? In order to answer the primary question properly, we must first focus on the secondary questions.

To determine student enthusiasm over the expanse of the study, interviews with half the class were given pre and post intervention and the entirety of the class participated within pre and post "Inquiry Education," surveys (Appendix C). Students' willingness and desire to participate in post-lab discussions were also monitored. As shown in Figure 1 on page 18, the surveys strongly supported the use of inquiry as a teaching method. However, students were also extremely strong in their opinions on the form of inquiry that should be utilized. As the survey results show, any question pertaining to open inquiry methods had a rating that decreased over the treatment period; however each question pertaining to guided inquiry methods had increased ratings.

Not only did the majority express that they preferred a lab that is already prepared for them, they were also able to clarify why they felt that way. The majority of students felt they were able to learn more because they were more focused on learning goals when

they were conducting a guided inquiry lab as opposed to open inquiry. However, even with the heavy use of open inquiry during this study, the number of students who felt that, “Science is fun, and so is discovering information through labs,” increased through the extent of the study. This is shown in Figure 2 on page 21.

Increase in student enthusiasm over science was also evident within their discussion participation. As shown in Table 5 on page 30, though the quantity of student comments did not necessarily increase, the quality did. Students were not required, but all were encouraged to participate within the discussions. In the first discussion, two students said they had nothing to add; whereas by the third discussion everyone felt they had valuable information to share, were anxious for their turn to share it, and would become frustrated by the dominant speakers that wanted to continue a discussion relating to other students’ data and observations. The whole class was disappointed when we were out of time for the discussion, and three students even stopped by after class to share observations with me that they had not had the opportunity to share with the rest of the students. As discussed previously, discussions also supplied strong evidence toward guided inquiry encouraging application of data to form strong connections and conclusions.

Unfortunately, the verbal discussions were the only opportunities for me to draw evidence that students had grown in their capabilities with drawing conclusions. As shown in Table 4, page 28, regardless of whether a student was working with a guided or open inquiry lab, their conclusion scores for their lab report did not increase a noteworthy amount. Even the extra exposure to regular lab reports and guidance through the rubric and expectations was not enough to increase students’ ability to draw conclusions and

make applications beyond direct data comparison. However, the fact that they were able to do so in the discussions is encouraging, because it shows confidence and critical thinking. Lab reports simply require a much greater amount of effort to write thorough applications and conclusions. And as the data show in Figure 4 on page 25, many students believe that the reports are, “A lot of work for a small amount of learning.” Within surveys and interviews, a large percentage of students did indicate that they wished for more group work opportunities, collaboration, and discussion. They feel they learn at a much higher extent when they are able to hear the content in the words of other students. Therefore, though I did not see extensive growth with the group through their lab report conclusions, I believe this is due to the lack of value they place upon them, rather than their abilities to draw and apply conclusions. Unfortunately, my hopes that open inquiry would provide this value is not supported.

When examining whether open inquiry encouraged research to help form a better lab design, data did not support this preface. Again looking at Table 4 on page 28, we can see that students' motivation to research did not increase throughout the extent of the study. This was true whether they were completing an open or guided inquiry lab. However, personal observations I made from student comments and individual reports were encouraging. By the third inquiry experience, 50% of the students participating in the guided inquiry lab had revised the given question to one that interested them more. They then conducted research surrounding that question. This showed evidence, that though they were excited to be a part of the guided inquiry group, they were drawn to the freedom that open inquiry provides. It also showed that their willingness to research did increase when their focus was pinpointed to one specific question. This observation is



what caused me to be so surprised by the negative connotations made toward open inquiry within the surveys and interviews. Again, all of the students' comments make it clear that they simply prefer the guidance because it increases their confidence in the lab design, and allows them to trust data as a valuable learning tool. Though the numbers are not capable of indicating this, students' research may not have increased by number of resources, or even volume, throughout the study; however, the research did become more focused around student questions as their abilities in inquiry grew.

As far as applying research to discussions, the stronger students who did research more would use their researched information within the discussions when data and conclusions were being debated.

Overall retention of knowledge through the use of inquiry was supported within the formative and summative assessments. The formative assessments showed a stronger correlation to learning with the use of open inquiry. This may have been due to the necessary understanding of information that is required of students in order for a lab to be designed. Open inquiry students may have been able to succeed more on formative assessments because they were more researched and prepared with background knowledge than the students conducting guided inquiry investigations. However, the data shifted when the summative assessment occurred. Units taught with guided inquiry, for groups A and B, scored higher within the Cells Unit Test. Both methods of inquiry were supported within this summative assessment, because these chapters within the unit scored higher than the chapters that were presented without the heavy use of inquiry techniques.

Through examining each sub question in detail, the answer to my primary question seems clear: inquiry improves student enthusiasm and retention of knowledge within a middle school science curriculum. This was proven through the Cells Unit Test, as well as in the Inquiry Post Test. When the post treatment inquiry scores were compared to their 6<sup>th</sup> Grade ISTEP results, a general increase with class averages was noted. The three components within ISTEP scores that relate to inquiry: Science, Engineering and Technology; The Nature of Science, and The Design Process averaged scores of 79%, 78%, and 77% respectively. The class was, at that point, above expected Indiana standards, and it is encouraging to see their continued growth in these areas of content (as is evident in Table 10, page 37). However, it is important to note, due to the focus of my tests, that guided inquiry had a much greater increase for student enthusiasm, application of knowledge, and a slight increase for retention of knowledge over longer periods of time. I do believe the use of open inquiry increased student abilities to make connections within guided inquiry, supporting the continued use of both techniques. This thought is supported by the strong desire for students to revise questions provided, and focus research on areas of interest as we progressed through the unit. I am glad to have data that support the use of inquiry for learning. Clarifying the strengths behind each approach is also wonderful information to have when planning my methods for teaching units and timing in future years.

#### VALUE

This particular study on various inquiry techniques has provided valuable data to apply within my teaching methods. Due to the extensive time and efforts that are required from using the inquiry approach, it is motivating to see that it is truly a successful means

for learning information. It has also been valuable to me to see that guided inquiry has such great strengths. Though I enjoyed watching the open inquiry process with my students, due to already limited time constraints it was encouraging to note that guided inquiry showed a greater extent of knowledge retention and student enthusiasm. When I compared the length of teaching this unit as compared to last year, I noticed a 40% increase in the time allotted for instruction over cells. An extension such as this for units, even with the applications and connections that open inquiry allows for, is unrealistic. The extent of a middle school curriculum could not be taught if each unit was expanded in this way. However, using open inquiry intermittently throughout the year, possibly once a quarter, would have definite benefits.

Students have shown extensive growth in their knowledge of inquiry and lab design, and I do not believe this would have been completely possible without the use of open inquiry in collaboration with guided inquiry tasks. Students have participated in completing Science Fair projects each year, and the final products of these efforts have increased extensively throughout my three years of observations. I believe students' increased exposure to inquiry throughout the extent of the year, rather than for one project, has allowed for this overall growth. Consistent use of inquiry has also made the Science Fair seem less tedious and cumbersome. However, Science Fair was occurring simultaneously with my intervention this year, and I do believe that concurrence may have caused an increase in the tedium students felt toward developing open inquiry work.

This project will affect my future teaching in many ways. Firstly, it has encouraged me to continue to apply inquiry with each unit. Results have proven that inquiry work does have lasting retention effects, and therefore supports the additional

efforts required for preparation and clean-up of labs. I also am able to recognize that open inquiry has its value in the classroom, but I believe utilizing it at a maximum of four times a year in correlation or as an extension of units would be sufficient. Originally I was considering applying open-inquiry with each unit, and now I recognize that this would be excessive and tiresome for all parties. I also realize that when applying the guided inquiry technique, I should allow flexibility in question development to encourage research and deeper student-connections to the labs. Lastly, I need to be sure to incorporate time for post-lab discussions and collaboration among students. This group of students has made clear the benefits they feel from discussion and lab collaboration. Even if the purpose was only to lower stress level for students, that alone holds high value. However, discussion and collaboration is also an extremely successful means for discovering and clarifying misconceptions among classmates. Therefore, the activities hold a high level of value, and time should be allotted for them.

I look forward to applying new techniques and methods to inquiry. I am anxious to observe students' scientific reasoning expand. I also anticipate my own further development in presentation of the inquiry approach to allow for maximum learning and enjoyment among students. I will continue to research and test new methods for encouraging applications of data that will allow thorough and pertinent conclusions to develop. I am excited that state and country school officials are recognizing the value of inquiry education, and I look forward to watching its continued development within our society.

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APPENDICES

APPENDIX A  
DISCUSSION PARTICIPATION SHEET



**Discussion Participation**

Date: \_\_\_\_\_ Discussion Number: \_\_\_\_\_

<b>Tally # of each Comment Type:</b>						
<b>Student</b>	<b>Agree/ Disagree</b>	<b>Repeat</b>	<b>Observations</b>	<b>Connections/ Conclusions</b>	<b>Argue/Defend</b>	<b>Quotes/ Observations</b>
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						

APPENDIX B  
INTERVIEW QUESTIONS

1. How would you define Science?
2. What are your feelings toward Science?
3. What is your favorite way to learn our science material when we are in class?
4. What methods help you to learn our material best?
5. What is your favorite way to learn our science material when you're at home?
6. Do you like creating your own labs?
7. Do you feel like you learn a lot when you create your own labs?
8. Do you enjoy doing labs I create?
9. Do you feel like you learn a lot from these labs?
10. Which lab experience do you feel like you learn the most from: When you design the lab, or when I design the lab?
11. What could make Science more enjoyable and easier for you to learn?

APPENDIX C  
INQUIRY EDUCATION SURVEYS

## Inquiry Education Survey

Please complete this survey honestly. It will have no effect on your grade, and any data that is shared beyond Mrs. McMullan will remain anonymous.

\* Required

**Please give your name and classroom number. \***

This information will help Mrs. McMullan analyze data, but will not be shared in any later reports.

**Choose the answer that best describes your current feelings toward Science. \***

- I think Science is fun, but I do not understand a lot of the information
- I think Science is easy, but boring.
- Science is interesting, but it is a lot of facts to have to memorize.
- Science is fun, and so is discovering information through labs.

**What do you think most helps you succeed in Science? \***

- Having a teacher that is willing to put in more effort
- Completing projects over the units
- Completing labs within each unit
- Taking notes over the material
- All of the above
- I am not successful in Science

**Choose the option that best describes your abilities to succeed in Science. \***

- Even if I try very hard, I do not do as well in Science as in other subjects.
- I can do well in Science, but I have to work harder than other subjects.
- I enjoy the work for Science, and am able to succeed by simply doing what is asked of me.
- I am able to succeed in Science without studying. It is easy for me.

**What causes you to be more successful in Science. \***

- My teacher teaching the information well.
- Studying my notes, doing weekly homework, and preparing for tests.
- Understanding the information at a deeper level through labs and projects.

- Working with a group throughout the unit so other students can explain the information in words I can understand.

**When you are not doing well in Science, what do you believe causes this? \***

- Too much focus on labs, and not enough time on notes.
- My teacher is not teaching it well.
- I am not doing my homework, or participating in class.
- Not enough labs and projects to help me understand and visualize the complex information.

**Who is most responsible for your achievement in Science? \***

- Student (self)
- Teacher
- Parents
- Classmates

**Lab days in school are \***

Please finish this statement

- fun, and I like them because I do not have to work very hard that day.
- useless. I do not learn from the experience, and have to waste my time writing a report.
- fun, but not helpful for me when it comes to learning the information we are studying.
- fun, and helpful.
- stressful, and therefore not helpful to me.

**Lab reports are... \***

Please finish this statement.

- A lot of work, for a small amount of learning.
- A lot of work, but they help me see the value of the lab.
- Easy, and helpful.
- Easy, but a waste of time.

**When asked to research for a Science inquiry project, I am excited to learn more about something that interests me. \***

1. Not at all true 2. Somewhat true 3. Mostly True 4. Completely true

1 2 3 4

---

Not at all true     Completely true

---

**I like being able to come up with my own questions and experiments to help me learn Science \***

1. Not at all true 2. Somewhat true 3. Mostly True 4. Completely true  
1 2 3 4

Not at all true ● ● ● ● Completely true

**I like when my teacher gives me questions and designs the experiments. I feel like I learn more from these labs. \***

1. Not at all true 2. Somewhat true 3. Mostly True 4. Completely true  
1 2 3 4

Not at all true ● ● ● ● Completely true

**I feel like I am good at designing labs that help me learn valuable information. \***

1. Not at all true 2. Somewhat true 3. Mostly True 4. Completely true  
1 2 3 4

Not at all true ● ● ● ● Completely true

**When I am finished with a lab, I feel like I better understand the information we are learning in class. \***

1. Not at all true 2. Somewhat true 3. Mostly True 4. Completely true  
1 2 3 4

Not at all true ● ● ● ● Completely true

**What would make lab days most beneficial to you?**

**What would help make lab reports strong learning tools?**

APPENDIX D  
LAB REPORT RUBRIC



CATEGORY	4	3	2	1
<b>Question</b>	The purpose of the lab or the question to be answered during the lab is clearly identified and stated. The question posed is testable and meets the goal objective presented to the students.	The purpose of the lab or the question to be answered during the lab is identified, but is stated in a somewhat unclear manner. The question posed is testable, and though it meets the objective, will not provide opportunity for extensive learning.	The purpose of the lab or the question to be answered during the lab is partially identified, and is stated in a somewhat unclear manner. The question posed is testable, but does not meet the goal objective.	The purpose of the lab or the question to be answered during the lab is erroneous or irrelevant. The question posed is not testable, and does not meet the goal objective.
<b>Hypothesis</b>	Hypothesized relationship between the variables and the predicted results is clear and reasonable based on what has been studied.	Hypothesized relationship between the variables and the predicted results is reasonable based on general knowledge and observations.	Hypothesized relationship between the variables and the predicted results has been stated, but appears to be based on flawed logic.	No hypothesis has been stated.
<b>Background Sources</b>	More than three reputable background sources were used. Material is used to help formulate a strong hypothesis, and summary is	Three reputable background sources are used. Material is used to help formulate the hypothesis and the summary is	Fewer than three sources; and some are not reputable. Material was not considered when forming the hypothesis, but the summary is translated into	Fewer than three resources are used, material is not considered when formulating the hypothesis and information is directly copied rather than put

	translated into student's own words.	translated into student's own words.	student's own words.	into student's own words.
<b>Conclusion</b>	Conclusion includes whether the findings supported the hypothesis, possible sources of error, and what was learned from the experiment. Connections are made to the current unit of study.	Conclusion includes whether the findings supported the hypothesis and what was learned from the experiment. Connections are made to the current unit of study.	Conclusion includes what was learned from the experiment. Connections are not made to the current unit of study.	Conclusion shows little effort and reflection.
<b>Analysis</b>	The relationship between the variables is discussed and trends/patterns logically analyzed. Predictions are made about what might happen if part of the lab were changed or how the experimental design could be changed.	The relationship between the variables is discussed and trends/patterns logically analyzed.	The relationship between the variables is discussed but no patterns, trends or predictions are made based on the data.	The relationship between the variables is not discussed.
<b>Scientific Concepts</b>	Report illustrates an accurate and thorough understanding of scientific concepts underlying the lab.	Report illustrates an accurate understanding of most scientific concepts underlying the lab.	Report illustrates a limited understanding of scientific concepts underlying the lab.	Report illustrates inaccurate understanding of scientific concepts underlying the lab.

APPENDIX E  
INQUIRY POST TEST

Name \_\_\_\_\_

Date \_\_\_\_\_

## Grade 6 Sample Items

IDOE : <http://www.doe.in.gov/assessment/istep-grades-3-8>

ISTEP+ Science Item Sampler

## Applications of Inquiry

1. Jenna rolled a small glass marble and a large glass marble down a ramp at the same time to see if the large marble would roll further than the small one. She repeated this investigation four times. The table below shows her results.

Distances Rolled by  
Marbles of Different Sizes

Trial	Small Marble (cm)	Large Marble (cm)
1	305	300
2	306	304
3	299	309
4	301	298

Which statement CORRECTLY describes information found in Jenna's table?

- A. The small marble rolled further than the large marble in trials 2 and 3.
- B. The large marble rolled further than the small marble in trials 1 and 4.
- C. The difference in distances rolled by the small marble is less than 8 centimeters.
- D. The difference in distances rolled by the large marble is less than 8 centimeters.

3. Ben was playing with his remote-controlled toy truck on the sidewalk in front of his home. He placed the control on low speed and let the truck travel 300 centimeters. He calculated that the speed of the truck was 54 centimeters per second.

Ben then put 50 grams of soil into the bed of the truck. He placed the control on low speed and let the truck travel the same 300 centimeters. Describe how the speed of the truck would be affected by adding the soil. Explain your answer.

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4. With the same toy truck loaded with 50 grams of soil, Ben placed the control on high speed and let the truck travel the same 300 centimeters. Describe how the speed of the loaded toy truck at high speed would compare to the speed of the loaded toy truck at low speed. Explain your answer.

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5. Mark is studying how long different animals usually live. He found information on four different animals. His data are listed below.

\*Black panthers live about 12 years in the wild and about 20 years in a zoo.

\*Giraffes live about 20 years in the wild and about 25 years in a zoo

\*Gorillas live about 35 years in the wild and about 50 years in a zoo.

\*River otters live about 8 years in the wild and about 21 years in a zoo.

Use the information Mark gathered to complete the DATA TABLE below.

How Long Animals Live

	Living in the Wild (years)	

According to the table, which animals live more than 15 years in the WILD?

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According to the table, which animal lives almost THREE times as long in a zoo as it does in the wild?

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Give ONE reason why all the animals Mark studied tend to live longer in a zoo than they do in the wild.

---

6. Laura wondered about how the amount of time a battery is charged affects the time a flashlight gives off light. She did the following investigation.

Question:

How does the amount of time a battery is charged affect the time the flashlight gives off light?

Prediction:

A flashlight should give off light for about the same amount of time as the batteries were charged because the energy put into the battery should be about the same as the energy out.

Materials:

uncharged batteries

battery charger

flashlight

timer

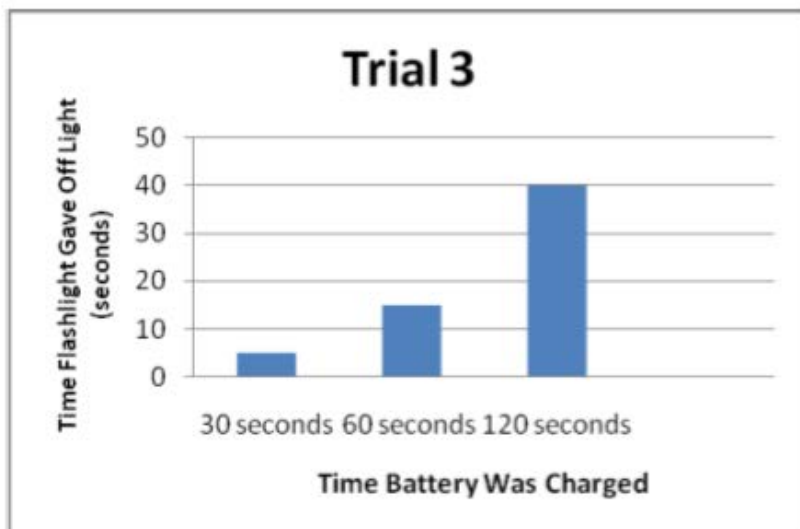
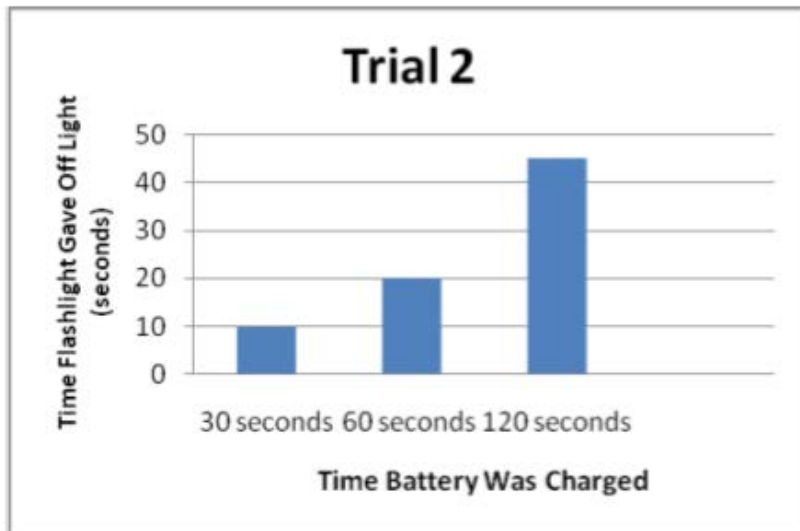
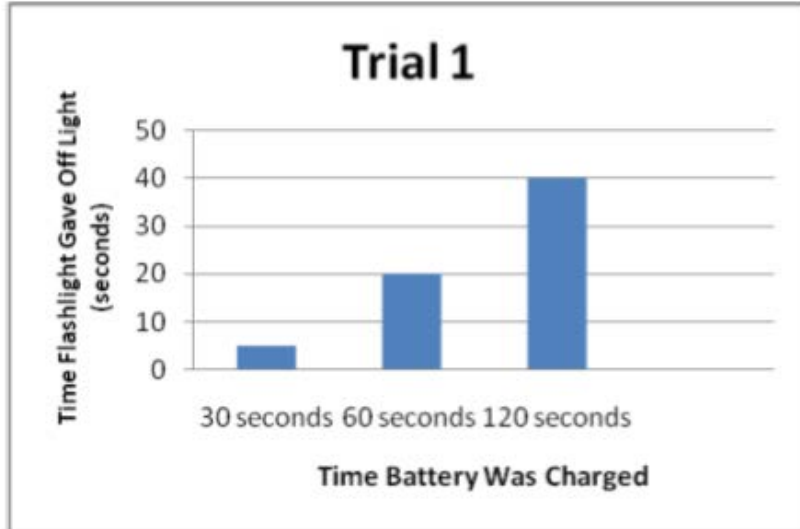
Procedure:

- a. Place 2 uncharged batteries in the charger. Turn on the charger for 30 seconds.
- b. Put the 2 charged batteries into the flashlight.
- c. Turn the flashlight on. Measure and record in the table the time the flashlight is giving off light as trial 1 for the amount of time the batteries were charged.
- d. Repeat steps 1-3 increasing the charging time from 30 seconds to 60 seconds, and to 120 seconds. Record the data in the table for each test.
- e. Repeat the entire investigation two more times as Trials 2 and 3.

Laura put her results in the data table below and created 3 bar graphs to display the data for each trial. *Using the bar graphs, fill in the missing information in the data table below.*

Time Battery Was Charged vs. Time Flashlight Gave Off Light

Time Battery was Charged (seconds)	Time Flashlight Gave Off Light (seconds)		
	Trial 1	Trial 2	Trial 3
30			
90			
120			





Why did Laura put her results in a table and graphs?

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Do the results shown in the table and graphs support Laura's prediction? Explain why or why not.

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APPENDIX F

CELL THEORY OPEN INQUIRY LAB GUIDELINES

## Cell Theory - Designing Tests to Support or Refute

We are beginning our unit of study on Cells. For this first section, you will all be learning more about cell theory by creating and conducting your own inquiry lab over a question that pertains to the Essential questions and/or cell theory.

The essential questions are:

Why are cells important?

How are new cells created?

How do the cells in single-celled and multi-cellular organisms differ?

What are the main characteristics of cells?

Cell Theory States:

1. The cell is the basic unit of life
2. All living things are made of one or more cells
3. All cells come from existing cells

Use the essential questions and/or cell theory to develop a testable question that will help you to better learn and understand this section. Your question can pertain to proving or disproving part or all of the cell theory, or it can work to answer/help you visualize one of the above Essential questions.

Your assignment, before Wednesday, January 15 is to develop a testable question, research facts related to your question (on DE or outside of the site), form a strong hypothesis based on your research , and write a thorough materials and procedures list. On Edmodo, I only need to see the question and a thorough hypothesis (that utilizes your research!). All of the components **MUST** be in your STEM notebook by Wednesday so you are ready to begin/complete your lab in class that day.

\*\*\*An assignment has been assigned to you on DE to help you with your research!\*\*\*

APPENDIX G  
PROKARYOTE INQUIRY DIRECTIONS

**Prokaryotic Cells**

Regardless of if you are creating your own lab, or completing the lab I have designed, you need to have background research completed to best understand what you are observing. Please complete the assignment on Discovery Ed and/or use any additional resources you find to help you with this.

When turning in this assignment you must state:

- 1: The number of resources you used/what they were
- 2: What topic(s) on which you focused your research
- 3: The important facts you learned that will help you better understand your experiment.

Students 9-16, attached are your lab options:

**Read the following experiments. Place a star next to the one of most interest to you.**

## **Bacteria Growing Experiments in Petri Plates**

### **Introduction**

Bacteria are microorganisms that grow everywhere. We can collect and grow them in specially prepared petri dishes. Blood agar or tryptic soy agar with 5% sheep's blood is an excellent medium for supplying bacteria with nutrients and an environment in which we can see them grow.

Sterile powdered agar with nutrients can be mixed with water, heated and then poured into empty petri plates or ready-to-use dishes can be purchased. The undigestible agar is a gelatin-like substance with a semi solid surface on which the bacteria can grow while they consume the added nutrients (like sheep's blood). In fact, this is why gelatin itself does not make a good growing medium. Some bacteria can digest gelatin, which is a protein derived from animal tissue. This destroys the growing surface in the petri plate making it unsuitable as a bacteria growth medium.

**CAUTION.** *Most bacteria collected in the environment will not be harmful. However, once they multiply into millions of colonies in a petri dish they become more of a hazard. Be sure to protect open cuts with rubber gloves and never ingest or breathe in growing bacteria. Keep growing petri dishes taped closed until your experiment is done. Then you should safely destroy the fuzzy bacteria colonies using bleach.*

Below are general outlines of three types of experiments involving bacteria growth. They are offered to assist in designing your own experiment or project.

### **Experiment 1: Direct Contact**

Discussion.

In this type of experiment, bacteria is transferred directly to the prepared petri plate via direct contact. You can test the effectiveness of different soaps by treating different petri dishes with "dirty" hands before washing and "clean" hands after washing. Or, you can press a variety of common objects like coins, combs, etc. on different plates and compare the bacteria growth that results.

What you need.

- Prepared petri plates containing agar medium and nutrients.  
*The Science Company has these available [at this link](#).*
- Bacteria on hands, paws, etc.
- Wax pencil for labeling dishes.
- Masking tape.
- Bleach.

What to do.

1. Prepared petri dishes should be refrigerated until used and always stored upside down (i.e media in upper dish, cover on bottom). This keeps condensation which forms in the lid from dropping onto and disrupting the bacteria growing surface.
2. When ready to use, let dishes come to room temperature before taking samples (about one hour).

3. Using a sharpee on the underside of the dish, divide the dish into 4 segments. Label each segment. Without tearing the agar surface, inoculate the dish by gently pressing fingers, finger nails, coin, etc onto agar surface. (Direct contact of lips or tongue is NOT a good idea.)
4. Replace cover on dish, tape closed, and check to be sure each dish is labeled so you know the source of the bacteria. Store upside down.
5. Let grow in undisturbed warm location. Bacteria can grow at any temperature from about ambient room temperature (hopefully around 70°F) all the way up to about 100°F. Do not place in sunlight or on a heating register.
6. You should see growth within a couple of days. The dishes will start to smell which means the bacteria are growing.
7. Make observations and keep records of what you see growing in each dish. Can you make any conclusions about what objects had the most bacteria?
8. Before disposing of dishes in the trash the bacteria should be destroyed. Pour a small amount of household bleach over the colonies while holding dish over sink. Caution - do not allow bleach to touch your skin, eyes or clothes. It will burn!

### **Experiment 2: Collected bacteria samples**

#### Discussion.

Use a sterilized inoculating loop or sterile swabs to collect bacteria from different locations and then streak each petri dish with your sample. This involves a bit more technique than Experiment 1 but offers a wider choice of bacteria sampling locations. Swabs can be run over doorknobs, bathroom fixtures, animal mouths, etc.

What you need.

- Prepared petri dishes containing agar medium and nutrients.  
*The Science Company has these available [at this link](#).*
- Bacteria collected from doorknobs, bathroom fixtures, etc.
- Wax pencil for labeling dishes.
- Masking tape.
- Sterile swabs or inoculating loop.
- Alcohol burner (source of flame to sterilize inoculating loop).
- Bleach.

What to do.

1. Prepared petri dishes should be refrigerated until used and always stored upside down (i.e media in upper dish, cover on bottom). This keeps condensation which forms in the lid from dropping onto and disrupting the bacteria growing surface.
2. When ready to use, let dishes come to room temperature before taking samples (about one hour).
3. Collect bacteria from each location using one swab (or reesterilized innoculating loop) for each new spot.
4. Divide each dish in half, labeling the halves with the bacteria source. Inoculate each dish by streaking a straight line gently across the agar about 1 cm from each edge.
5. Replace cover on dish, tape closed, and be sure each section is labeled so you know the source of the bacteria. Store upside down.

6. Let grow in undisturbed warm location, ideally in an environment around 100° F (37° C) - not in sunlight or on a heating register.
7. You should see growth within a couple of days. The dishes will start to smell which means the bacteria are growing.
8. Make observations and keep records of what you see growing in each dish. Can you make any conclusions about what locations had the most bacteria?
9. Before disposing of dishes in the trash the bacteria should be destroyed. Pour a small amount of household bleach over the colonies while holding dish over sink. Caution - do not allow bleach to touch your skin, eyes or clothes. It will burn!

### **Experiment 3: Testing the effectiveness of bacteria killing agents**

#### Discussion.

In this type of project, a petri dish is inoculated with bacteria then a paper disk (filter paper) treated with an antiseptic agent is placed in the dish. After several days, a halo develops around the paper disk indicating a zone of no growth. Comparisons can be made between different antibacterial agents.

#### What you need.

- Prepared petri dishes containing agar medium and nutrients.  
*The Science Company has these available [at this link](#).*
- Bacteria collected from doorknobs, bathroom fixtures, etc.
- Wax pencil for labeling dishes.
- Masking tape.
- Sterile swabs or inoculating loop.
- Alcohol burner (source of flame to sterilize inoculating loop).
- Antibacterial agent (soaps, disinfectants, etc.).
- Sterile water.
- Test tubes, 12 x 75mm.
- Filter paper or paper towel.
- Small containers in which to soak paper disks.
- Hole punch.
- Tweezers.
- Ruler.
- Bleach.

#### What to do.

1. Prepared petri dishes should be refrigerated until used and always stored upside down (i.e media in upper dish, cover on bottom). This keeps condensation which forms in the lid from dropping onto and disrupting the bacteria growing surface.
2. Prepare sterilized water by boiling water and letting cool to room temperature.
3. When ready to use, let petri dishes come to room temperature before taking samples (about one hour).
4. Prepare antiseptic disks by using a hole punch to create paper disks out of a piece of filter paper or paper towel. Soak one disk in each antibacterial agent to be tested. Set aside until step 6.
5. Collect bacteria from two locations using using a sterile swab for each spot.



6. Fill a small test tube partly full of sterilized water. Dip bacteria laden swab into water. This will transfer some of the bacteria you collected into the water. Now, inoculate a petri dish by pouring the water into the dish so the entire surface is covered. Pour out excess water. Repeat for both bacteria samples using fresh water and clean test tube each time.
7. Separate your dish into the number of quadrants you have, equal to the number of antiseptics you are testing. Label each section with the name of the antiseptic the disk is treated with. Place your pretreated antiseptic disks (up to four), one in each section of the inoculated petri dish.
8. Replace cover on dish, tape closed, store upside down. Be sure to label each petri dish with a name or number.
9. Let grow in undisturbed warm location, ideally in an environment around 100° F (37° C) - not in sunlight or on a heating register.
10. You should see growth within a couple of days. You should also see a "halo" around each disk indicating a no growth zone. Measure and compare the size of the kill zone to determine effectiveness of each antibacterial agent.
11. Before disposing of dishes in the trash the bacteria should be destroyed. Pour a small amount of household bleach over the colonies while holding dish over sink. Caution - do not allow bleach to touch your skin, eyes or clothes. It will burn!

#### Feedback

There are many variations of the basic steps outlined above. Let us know what you tested and how your experiment turned out. We'd be delighted to hear from you! [Click here and use our Contact Us form.](#)

**Once you have identified the experiment that interests you most, begin filling out your report on the attached sheets of paper. Create a testable question that this designed lab will help answer. Conduct background research. And write your hypothesis, based on information from this research. Lastly, create any data tables that you believe will be helpful to you in the lab conducted on Wednesday.**





APPENDIX H

MITOSIS AND CELL DIVISION INQUIRY DIRECTIONS

## Cell Cycle and Mitosis Lab

This week's assignment is to help you prepare for next week's lab. Numbers 1-8 will have a lab designed by me to conduct, and numbers 9-16 will conduct their own researched lab. You are all expected to complete research prior to these labs, as well as form hypothesis from this research. Attached to this assignment is one website that contains vast amounts of information on the cell cycle and mitosis, but please feel free to use more resources. Also, please contact me if you need help forming a lab question and test. You are welcome to use the ideas of others that you have researched to help you! (I just spent an hour looking at labs designed by others to help me form this assignment.)

On Edmodo you must turn in:

1. The question you are working toward answering
2. A summary of important information you researched and a citation of the sources you utilized. You should use more than one source! (I used about 20 this morning)
3. Your hypothesis formed due to this information

\*\*\*Note - last week's assignment on cell cycle and mitosis is full of resources as well to help!\*\*\*

Numbers 1-8, your lab is attached.

# *Stages of Mitosis*

Name \_\_\_\_\_

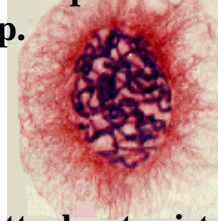
## *Introduction*

Mitosis, also called karyokinesis, is division of the nucleus and its chromosomes. It is followed by division of the cytoplasm known as cytokinesis. Both mitosis and cytokinesis are parts of the life of a cell called the Cell Cycle. Most of the life of a cell is spent in a non-dividing phase called Interphase. Interphase includes G1 stage in which the newly divided cells grow in size, S stage in which the number of chromosomes is doubled and appear as chromatin, and G2 stage where the cell makes the enzymes & other cellular materials needed for mitosis.

Mitosis has 4 major stages --- Prophase, Metaphase, Anaphase, and Telophase. When a living organism needs new cells to repair damage, grow, or just maintain its condition, cells undergo mitosis.

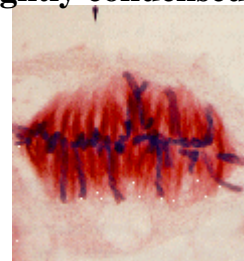
During Prophase, the DNA and proteins start to condense. The two centrioles move toward the opposite end of the cell in animals or microtubules are assembled in plants to form a spindle. The nuclear envelope and nucleolus also start to break up.

Prophase



During Metaphase, the spindle apparatus attaches to sister chromatids of each chromosome. All the chromosomes are lined up at the equator of the spindle. They are now in their most tightly condensed form.

Metaphase



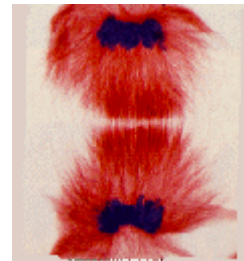
**During Anaphase, the spindle fibers attached to the two sister chromatids of each chromosome contract and separate chromosomes which move to opposite poles of the cell.**

**Anaphase**



**In Telophase, as the 2 new cells pinch in half (animal cells) or a cell plate forms (plant cells), the chromosomes become less condensed again and reappear as chromatin. New membrane forms nuclear envelopes and the nucleolus is reformed.**

**Telophase**



***Objective:***

**In this lab, you will determine the approximate time it takes for a cell to pass through each of the four stages of mitosis. You may use your textbook and class notes to help you identify the stages of mitosis as seen under the microscope.**

***Question:***

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***Research (site your sources!):***

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**Hypothesis:** \_\_\_\_\_

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**Materials:**

Microscope, prepared slide onion root tip, lab worksheet, pencil

**Procedure:**

1. Set up a compound light microscope and turn on the light.
2. Place a slide containing a stained preparation of the *Allium* (onion root tip) or Whitefish blastula.
3. Locate the meristematic or growth zone, which is just above the root cap at the very end of the tip or
4. Focus in on low power, and then switch to medium or high power. Below find micrographs of the four stages of mitosis. Use them to help you identify the stages on the microscope slide.
5. Now count the number of cells found in each stage of mitosis and place the data in the chart below.
6. Determine the percentage of time each cell will spend in each stage of mitosis. Divide the number of each cell by the total number of cells and multiply by 100 to determine the percentage. Place these values in the chart below.

**Data:**

Stage of Mitosis	Number of Cells	Percent of time in each stage =	
		$\frac{\# \text{ of cells in stage}}{\text{Total \# of Cell}}$	X 100%
Prophase			%
Metaphase			%
Anaphase			%
Telophase			%
Interphase (Not a Mitotic Stage)			%



<b>Total # cells</b>		<b>100%</b>
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Prophase (onion)



Metaphase (onion)

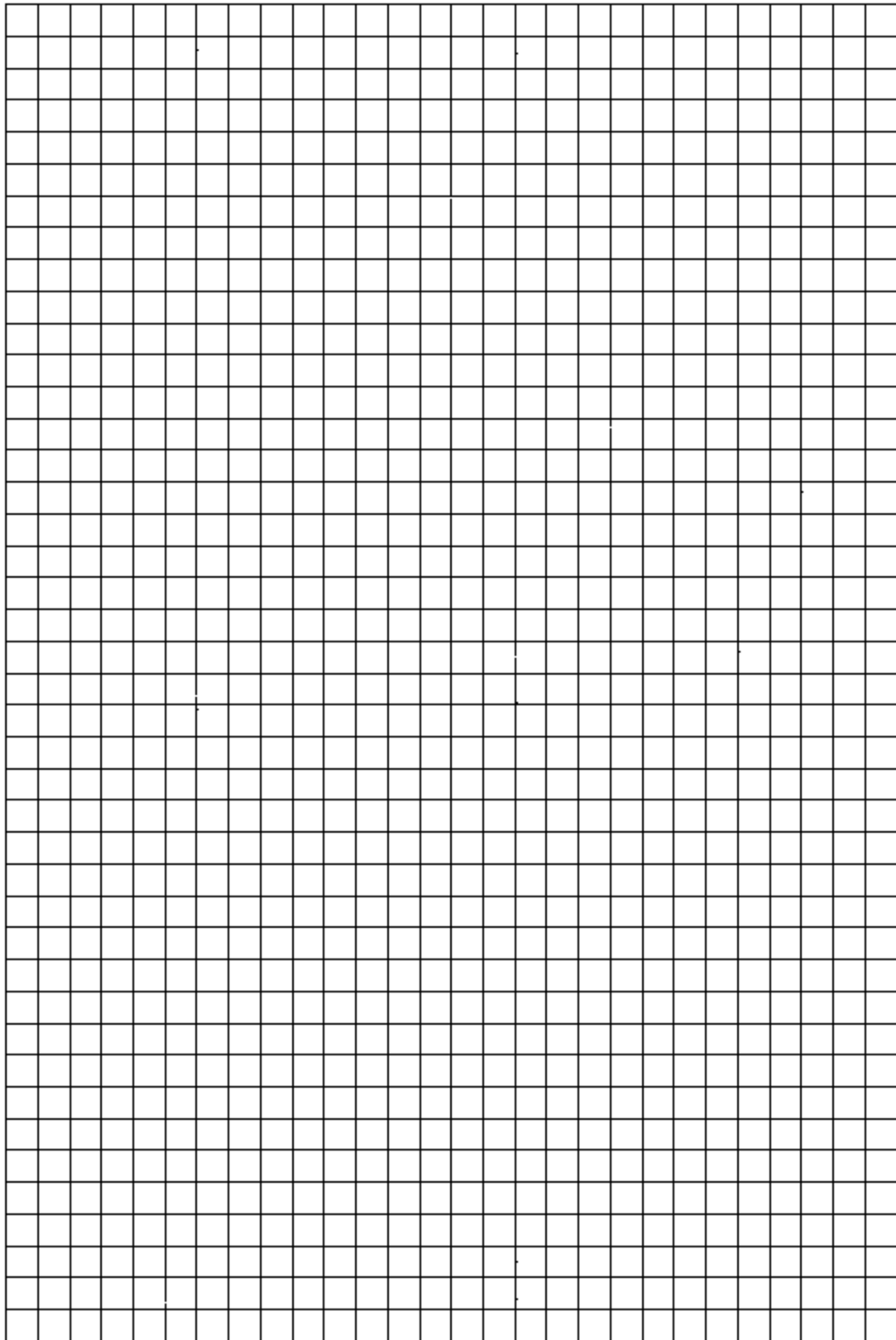


Anaphase (onion)



Telophase (onion)

**7. Line graph the data you have just collected. Be sure to label the X and Y axis & include the units of measurement.**

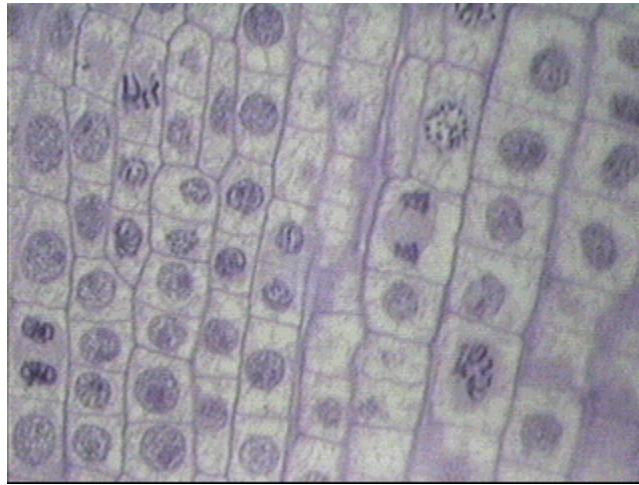


**Graph Legend:**



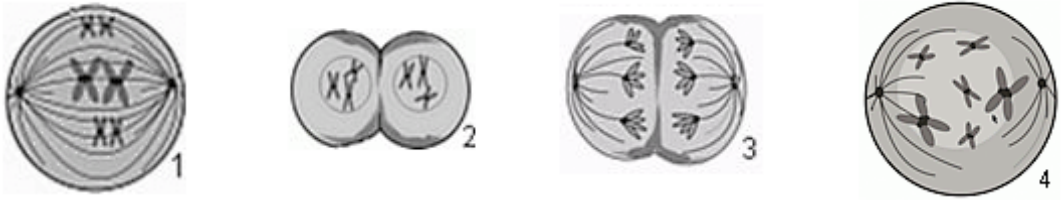
***Further Study:***

Normal Cell Division may be observed in onion root tips. Many of the processes are similar to those in animal cells. However, in plant cells, the cell plate between daughter cells forms from the Golgi.



Find all of the stages of mitosis and interphase in the above picture. Make a sketch of each stage and briefly describe what is occurring. Count and record the number of cells you see in each stage.

APPENDIX I  
CELLS UNIT TEST RESULTS

Class: Assessment: Cells Unit Test Attempt: 1						
Question	Performance Ratio	Students that Received Question	By Item			
			A	B	C	D
<b>Cell Cycle and Mitosis</b>						
<p><b>During which part of the cell cycle does the cell spend most of its time?</b></p> <p>A) anaphase B) prophase <b>C) interphase</b> D) telophase</p>	76.90%	13	1	2	10	0
<p><b>The following pictures show the four phases of mitosis. Which of the following is the correct order of events from the beginning to the end of mitosis?</b></p>						
<p>1 METAPHASE      2 TELOPHASE      3 ANAPHASE      4 PROPHASE</p> 						
D) 2-1-3-4	100.00%	13	0	0	13	0
<p><b>The two main parts of the cell cycle are:</b></p> <p>A) prophase and meiosis <b>B) interphase and mitosis</b> C) budding and binary fission D) photosynthesis and respiration</p>	76.90%	13	1	10	1	1
<p><b>What are the stages, or phases, of mitosis?</b></p> <p>A) interphase, tropophase, exophase, mesophase B) interphase, stratophase, ionophase, hydrophase C) lithophase, biophase, hydrophase, atmophase <b>D) prophase, metaphase, anaphase, and telophase</b></p>	100.00%	13	0	0	0	13
<p><b>What happens during interphase?</b></p> <p>A) budding <b>B) cell growth and DNA replication</b> C) binary fission D) separation of chromatids</p>	100.00%	13	0	13	0	0
<p><b>What is the process that cells</b></p>	100.00%	13	0	13	0	0

<p><b>undergo to divide?</b></p> <p>A) photosynthesis  <b>B) mitosis</b>          C) fusion          D) protein synthesis</p>					
<p><b>What is the purpose of mitosis in single-celled organisms?</b></p> <p>A) reproduction          B) replacement of worn-out cells          C) growth</p>					

Parent cell

**Mitosis**

Two daughter cells

10 2 1 0

0 0 1 12

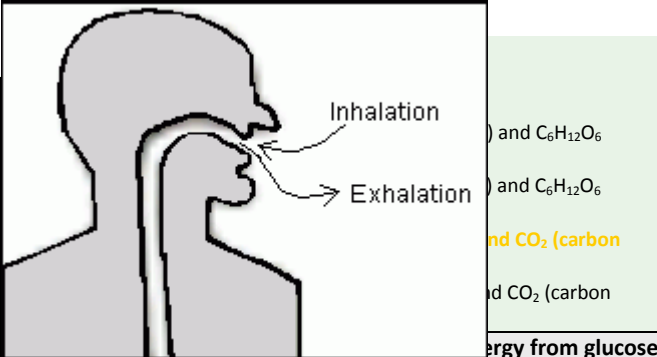
13 2 1 0 10

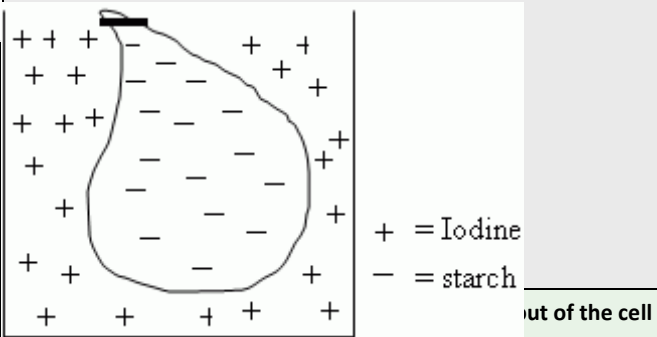
<p>A) identical to the other          B) almost identical to the other          C) about half identical to the other          D) not identical to the other</p>	92.30%	13	12	1	0	0
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**Cell Theory**

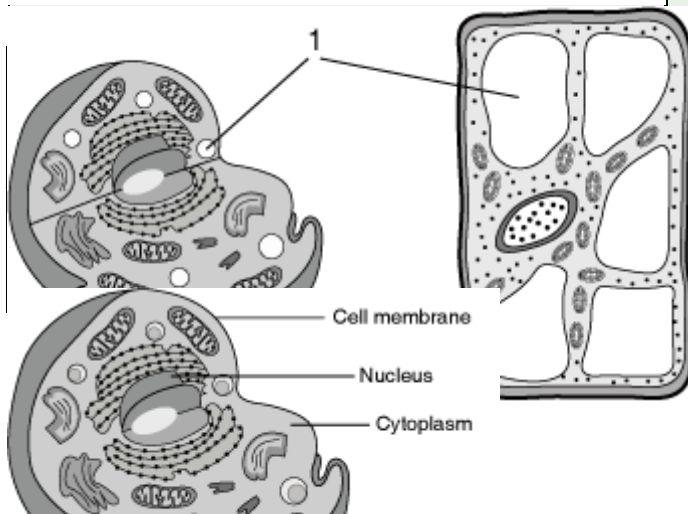
<p><b>The smallest unit of a living thing is called:</b></p> <p>A) a tissue  <b>B) a cell</b>          C) an organ</p>	100.00%	13	0	13	0	0
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D) a plasmid							
<p><b>Which of the following statements is true about all cells?</b></p> <p>A) They are all part of tissues.</p> <p>B) They all contain chlorophyll.</p> <p>C) They all have a cell wall.</p> <p><b>D) They all have a cell membrane.</b></p>	61.50%	13	5	0	0	8	
<b>Cellular Respiration</b>							
<p><b>All cells require energy. Which organelle releases energy from food and then stores that energy in molecules that the cell can use in other cell processes?</b></p> <p>A) a central vacuole</p> <p><b>B) a mitochondrion</b></p> <p>C) a lysosome</p> <p>D) a chloroplast</p>	69.20%	13	3	9	0	1	
<p><b>Identify the conversion made by the process of respiration.</b></p>							
 <p>A) O<sub>2</sub> and C<sub>6</sub>H<sub>12</sub>O<sub>6</sub></p> <p><b>B) O<sub>2</sub> and C<sub>6</sub>H<sub>12</sub>O<sub>6</sub></b></p> <p>C) O<sub>2</sub> and CO<sub>2</sub> (carbon)</p> <p>D) O<sub>2</sub> and CO<sub>2</sub> (carbon)</p>	46.20%	13	1	6	6	0	
<p><b>_____ energy from glucose and makes it into usable energy for the body is called _____.</b></p> <p>A) cellular fermentation</p> <p>B) anaerobic respiration</p> <p>C) aerobic fermentation</p> <p><b>D) cellular respiration</b></p>	84.60%	13	0	1	1	11	
<b>Diffusion and Osmosis</b>							
<p><b>A red blood cell is placed in a beaker of pure water. Which statement correctly depicts what will immediately occur?</b></p> <p>A) No movement of water will occur.</p> <p>B) Water will move out of the blood cell.</p> <p>C) The cell will decrease in size.</p> <p><b>D) Water will move into the blood cell.</b></p>	92.30%	13	0	1	0	12	
<p><b>A sealed bag containing starch solution is placed into a beaker that contains iodine. The bag is permeable only to iodine. Which statement correctly describes what will occur?</b></p>	76.90%	13	2	10	1	0	

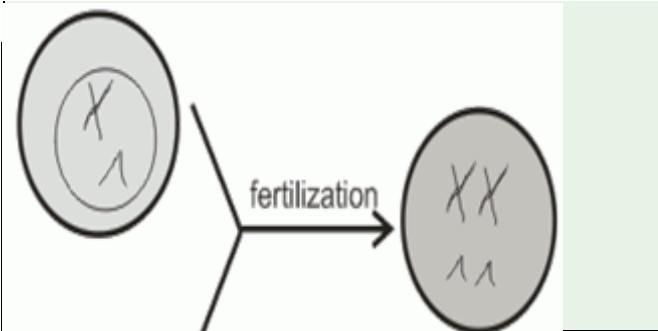
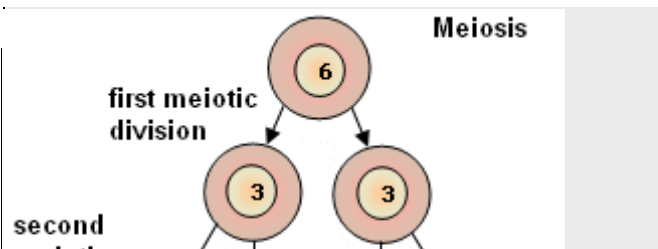
 <p>through the cell membrane.</p>					
<p>A) waste  <b>B) water</b>            C) oxygen            D) food</p>	92.30%	13	1	12	0 0
<p><b>When a plant cell is placed in distilled water, water molecules move into the cell. When a plant cell is placed in salt water, it loses water to the surrounding solution. Why does this occur?</b></p> <p>A) The water molecules are moving from an area of low concentration to an area of high concentration.  <b>B) Water molecules diffuse from areas of high concentration to areas of low concentration.</b>            C) The movement of water is associated with the temperature of the water            D) The salt eats away at the cell membrane and causes it to collapse.</p>	61.50%	13	2	8	0 3
<p><b>When a plant cell is placed in water, the plant cell will swell and become larger. What cell process is responsible for the movement of water into the cell?</b></p> <p>A) cellular respiration            B) active transport            C) translation  <b>D) osmosis</b></p>	100.00%	13	0	0	0 13
<p><b>Which of the following describes the way substances diffuse in and out of a cell?</b></p> <p><b>A) Substances move from greater to lesser concentration.</b>            B) Substances move from lesser to greater concentration.            C) Substances move back and forth across the membrane equally.            D) Substances move across the membrane when energy is available.</p>	69.20%	13	9	2	1 1
<b>Eukaryotic Cells and Cell Differentiation</b>					
<p><b>Which of the following structures would be observed surrounding only plant cells?</b></p> <p><b>A) cell wall</b>            B) chloroplast            C) cell membrane            D) cytoplasm</p>	100.00%	13	13	0	0 0

<p><b>Cells that are similar in structure and function are joined together to form:</b></p> <p>A) organelles                  B) prokaryotes  <b>C) tissues</b>                  D) nuclei</p>	61.50%	13	5	0	8	0
<p><b>Humans start from a single cell. Eventually, as cells divide, they start to differentiate, or specialize. Some cells are specialized for movement of the human body. What type cells would these be?</b></p> <p>A) <b>muscle cells</b>                  B) nerve cells                  C) bone cells                  D) skin cells</p>	38.50%	13	5	3	1	4
<p><b>Identify what causes types of cells to differ.</b></p> <p>A) Golgi bodies                  B) mitochondria  <b>C) genes</b>                  D) cell membrane</p>	84.60%	13	2	0	11	0
<p><b>If the concentration of water in the cytoplasm is less than the concentration outside the cell,</b></p> <p>_____.</p> <p>A) <b>water would flow into the cytoplasm through the cell membrane until its concentration was balanced on either side</b>                  B) water would flow out of the cytoplasm through the cell membrane until its concentration was balanced on either side                  C) water would flow into the cytoplasm through the cell membrane until the cell exploded                  D) water would flow out of the cytoplasm through the cell membrane until the cell dried up</p>	69.20%	13	9	3	0	1
<p><b>If you were looking at cells under a microscope, what would cause you to believe that the cells you were looking at were plant cells?</b></p> <p>A) <b>a large vacuole</b>                  B) small vacuoles                  C) cytoplasm                  D) a cell membrane</p>	100.00%	13	13	0	0	0



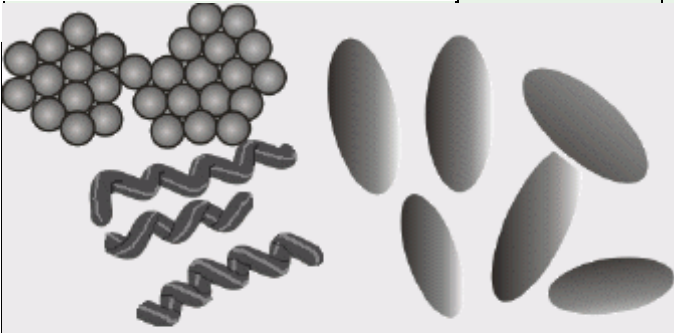
92.30%	13	12	0	0	1
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<p><b>Look at the diagram to answer the question.</b></p> <p><b>Which cellular structure helps in transferring genetic information from one generation to another?</b></p> <p>A) nucleus</p> <p>B) cytoplasm</p> <p>C) mitochondria</p> <p>D) cell membrane</p>	84.60%	13	11	0	1	1
<p><b>Most organelles are _____.</b></p> <p>A) suspended in the cytoplasm surrounded by a membrane</p> <p>B) suspended in the cytoplasm surrounded by a wall</p> <p>C) suspended in the cytoplasm free of any membrane</p> <p>D) suspended in the cytoplasm free of any wall</p>	69.20%	13	9	4	0	0
<p><b>The role of the cell membrane is to:</b></p> <p>A) produce glucose for the cell.</p> <p>B) direct reproduction of the cell.</p> <p>C) regulate what enters and leaves the cell.</p> <p>D) carry out respiration to get energy for the cell.</p>	84.60%	13	0	2	11	0
<p><b>The three most important differences between plant and animal cells are that plant cells _____.</b></p> <p>A) have small vacuoles, cytoplasm, and lack mitochondria</p> <p>B) have cell walls, chlorophyll, and a large, central vacuole</p> <p>C) vary greatly in appearance, have a cell membrane, and mitochondria</p> <p>D) lack chloroplasts and ribosomes, and have an irregular shape</p>	100.00%	13	0	13	0	0
<p><b>Which of the following choices shows the correct order of organization from the most simple to the most complex?</b></p> <p>A) organs, tissues, systems, organisms</p> <p>B) tissues, cells, systems, organisms</p> <p>C) cells, tissues, organs, systems</p> <p>D) systems, organs, tissues, cells</p>	76.90%	13	1	1	10	1
<p><b>Which organelle serves as a storage space in a cell?</b></p> <p>A) Golgi body</p> <p>B) vacuole</p> <p>C) endoplasmic reticulum</p> <p>D) lysosome</p>	100.00%	13	0	13	0	0
<b>Meiosis</b>						
<p><b>Female gametes are also known as _____ cells.</b></p> <p>A) egg</p> <p>B) sperm</p> <p>C) zygote</p> <p>D) diploid</p>	84.60%	13	11	0	0	2

<p><b>How many nuclear divisions occur during meiosis?</b></p> <p>A) 1  <b>B) 2</b>            C) 3            D) 4</p>	<p>84.60%</p>	<p>13</p>	<p>0 11 0 2</p>
<p><b>If normal human cells contain 46 chromosomes, how many chromosomes do sperm and egg cells have?</b></p> <p>A) 12.5  <b>B) 23</b>            C) 46            D) 92</p>	<p>84.60%</p>	<p>13</p>	<p>0 11 2 0</p>
<p><b>Look at the graphic.</b></p>			
	<p>46.20%</p>	<p>13</p>	<p>5 6 0 2</p>
<p>C) both sexual and asexual reproduction            D) neither sexual nor asexual reproduction</p>	<p>92.30%</p>	<p>13</p>	<p>12 0 1 0</p>
<p><b>Meiosis results in cells that have only half the number of chromosomes of the parent cell. The full number of chromosomes is later restored by:</b></p> <p>A) mitosis            B) binary fission  <b>C) fertilization</b>            D) polarization</p>	<p>92.30%</p>	<p>13</p>	<p>1 0 12 0</p>
<p><b>The nuclei that result from meiosis contain_____.</b></p>			
	<p>69.20%</p>	<p>13</p>	<p>2 2 9 0</p>

D) sometimes more or less genetic material as the starting nucleus						
<b>The two nuclear divisions of meiosis result in _____ daughter cells</b>						
A) 4						
B) 2						
C) 3						
D) 6	92.30%	13	12	1	0	0
<b>When two gametes join they make _____.</b>						
A) a diploid cell						
B) a haploid cell						
C) sometimes a diploid cell and sometimes a haploid cell						
D) neither diploid nor haploid cells	53.80%	13	7	5	0	1
<b>Which of the following events take place during meiosis but not mitosis?</b>						
A) DNA replication						
B) two diploid cells						
C) four haploid cells						
D) Spindle fibers attach to chromosomes.	76.90%	13	0	3	10	0
<b>Photosynthesis</b>						
<b>Animal cells cannot carry out photosynthesis because they lack _____.</b>						
A) mitochondria						
B) a cell wall						
C) the Golgi apparatus						
D) chloroplasts	100.00%	13	0	0	0	13
<b>How is the sugar produced by photosynthesis used?</b>						
A) Only plants use it as food.						
B) Only animals use it as food.						
C) Plants and animals use it as food.						
D) It is not used.	23.10%	13	10	0	3	0
<b>In photosynthesis, plant cells use _____ to trap light energy and produce glucose.</b>						
A) chloroform	76.90%	13	1	10	0	2

B) chlorophyll C) ribosomes D) respiration							
<b>The process of photosynthesis produces:</b> A) glucose and chlorophyll B) glucose and oxygen C) oxygen and carbon dioxide D) glucose and carbon dioxide	84.60%	13	0	11	1	1	
<b>What are carbon dioxide (CO<sub>2</sub>) and water (H<sub>2</sub>O) converted into as a result of photosynthesis?</b> A) O <sub>2</sub> (oxygen) only B) C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> (glucose) only C) O <sub>2</sub> (oxygen) and C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> (glucose) D) neither O <sub>2</sub> (oxygen) nor C <sub>6</sub> H <sub>12</sub> O <sub>6</sub> (glucose)	100.00%	13	0	0	13	0	
<b>Which of the following is provided directly by the sun to plants for photosynthesis?</b> A) oxygen B) energy C) carbon dioxide D) glucose	100.00%	13	0	13	0	0	
<b>Prokaryotic Cells</b>							
<b>_____ are prokaryotes that can cause various diseases.</b> A) Viruses B) Bacteria C) Protists D) Fungi	84.60%	13	1	11	0	1	
<b>Prokaryotes that do not require oxygen to live are:</b> A) anaerobes B) viruses C) aerobes D) plasmids	76.90%	13	10	0	3	0	
<b>Prokaryotes that make their own food are:</b> A) autotrophs B) plants C) protists D) heterotrophs	69.20%	13	9	2	1	1	
<b>Prokaryotic cells tend to be _____ than eukaryotic cells.</b> A) larger B) smaller	61.50%	13	2	8	2	1	

C) more complex						
D) less numerous						
<b>The genetic material in prokaryotes is:</b>						
A) protein						
B) lipids						
<b>C) DNA</b>						
D) sugar	69.20%	13	3	1	9	0
<b>Which is not a common shape for prokaryotic cells?</b>						
						
<b>different types of prokaryotic cells</b>			13	12	0	0
<b>C) Prokaryotes can be harmful or helpful to humans.</b>						
D) Prokaryotes have no effect on humans.	84.60%	13	1	1	11	0

Score Legend 85% — 100% is green 70% — 84% is orange 0% — 69% is red